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AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON.

DIVISION OF AGRICULTURE
Soil Physics

A Soil Survey of the Proposed Palouse Irrigation Project

By
H. F. Holtz

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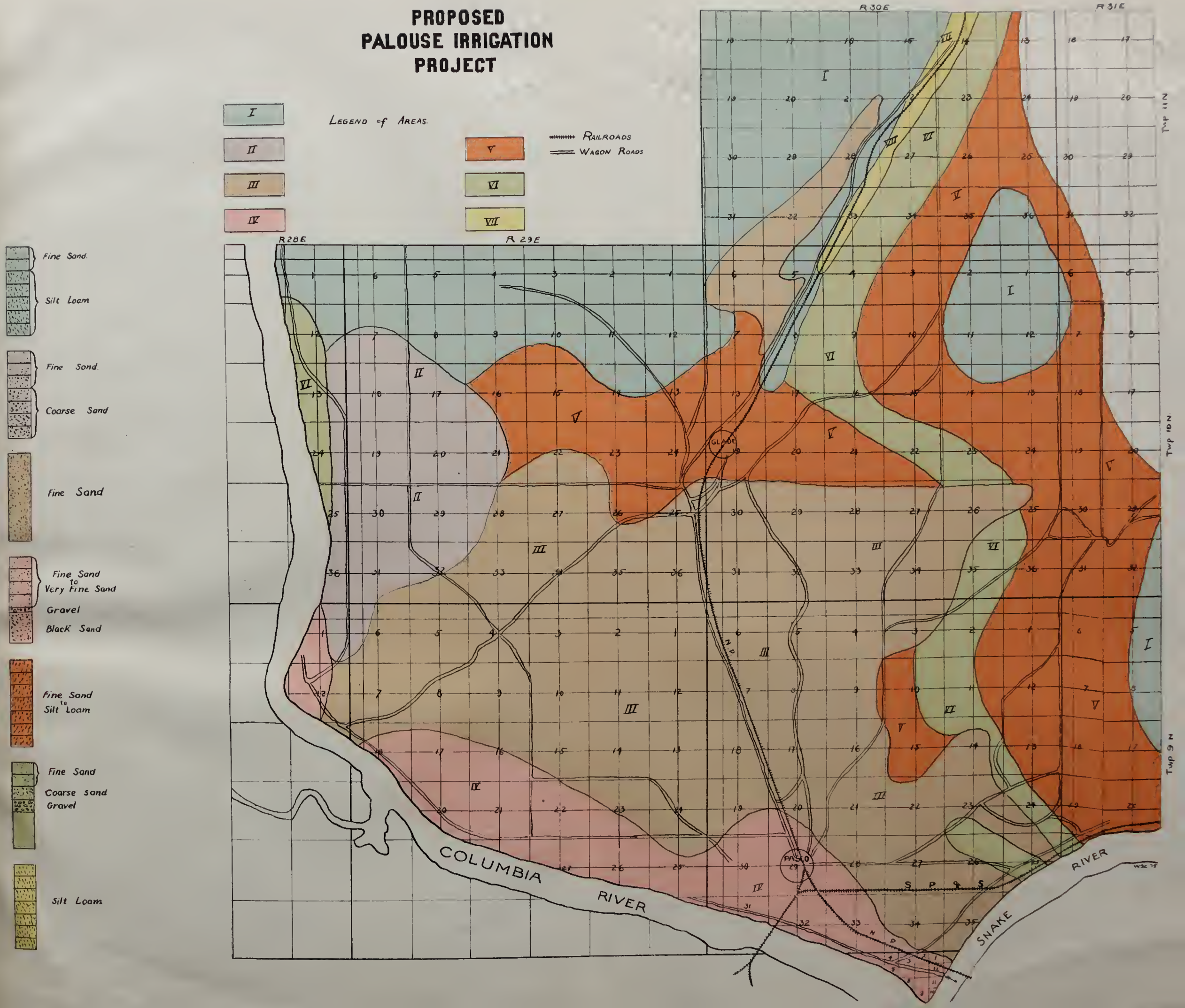
Fine Sand.
Silt Loam
Fine Sand.
Coarse Sand.
Fine Sand
Fine Sand to Very Fine Sand
Gravel
Black Sand
Fine Sand to Silt Loam
Fine Sand
Coarse sand
Gravel
Silt Loam
I
II
III
IV
V
VI
VII
R 31 E
Twp 11 N
Twp 10 N.
Twp. 9 N
SNAKE RIVER
P & S
WSC '15



PROPOSED
PALOUSE IRRIGATION
PROJECT
LEGEND OF AREAS.
I
II
III
IV
V
VI
VII
RAILROADS
WAGON ROADS
Fine Sand.
Silt Loam
Fine Sand.
Coarse Sand
Fine Sand
Fine Sand to Very Fine Sand
Gravel
Black Sand
Fine Sand to Silt Loam
Fine Sand
Coarse Sand
Gravel
Silt Loam
R 28 E
R 29 E
R 30 E
R 31 E
Twp 11 N
Twp 10 N
Twp 9 N
GLADE
PASCO
N. P.
S. P. & S.
COLUMBIA RIVER
SNAKE RIVER

A SOIL SURVEY OF THE PROPOSED PALOUSE IRRIGATION PROJECT

By H. F. Holtz, Assistant Soil Physicist

INTRODUCTION

The Soil Survey of the the proposed Palouse Irrigation Project was made at the request of the United States Department of Interior as a part of the investigation regarding the feasibility of developing this area of land.* The project is located in the southern part of Franklin County, Washington, in the confluence of the Columbia and Snake rivers, comprising the greater part of Townships 9 and 10, Ranges 29, 30 and 31,—in all 103,000 acres. The survey covered the investigation of such factors as are necessary to make this a permanent and profitable irrigation project. This included the study of, (1) Topography, (2) Geological formation, (3) Vegetation, (4) Water Holding Capacity, (5) Physical Analysis, (6) Chemical Analysis, for the four essential plant food elements, viz. Nitrogen, Phosphorus, Calcium and Potash.

TOPOGRAPHY

The project as a whole has a gentle southwesterly slope toward the Columbia river. The elevation ranges from 350 feet above sea level at the Columbia river to 700 feet in the northern part of the Project. The inclination is about 300 feet in 15 miles. The surface is rollng. The majority of the lands will have to be leveled before they are put under cultivation.

GENERAL GEOLOGICAL FORMATION

The Palouse Irrigation Project lies within the section of the country that was once the bed of an old lake. Since this time the Snake and the Columbia Rivers have cut their channels thru this lake bed formation exposing different

*Acknowledgement is made to the United States Department of Interior for a field assistant who acted as locator. Acknowledgement is made also to Mr. P. A. Devers for the photographs used in this bulletin, and to Professor C. C. Thom for valuable suggestions during the progress of the work.

layers of soil. These different soil strata do not lie in a horizontal plane, but have a downward inclination of about 100 feet in 20 miles, from the northwest to the southeast. A cross section of this stratification would show the underlying layer to be coarse blue-black sand with an occasional boulder. Overlying this blue-black sand is a mixed layer of shot gravel and ashy material which is somewhat packed or cemented together. Upon this layer of shot gravel and ashy material is a fine silt loam which is the predominating soil type of Central Eastern Washington.

From the soil stratification and the slope of the Project, it is evident that the different soil strata will appear on the surface and form the surface soil at different elevations. Proceeding from the Columbia River in a northeasterly direction, the coarse blue-black sand will form the surface soil, next the shot gravel and ashy material and lastly the fine silt loam. These surfaces have, however, been modified by the action of the wind, which has carried a fine sandy loam across the Columbia River and deposited it upon and mixed it with the original soil strata. The wind action will be discussed more fully under the drift area.

METHODS

A field study was made of this project when the samples were taken and both characters and change of the vegetation were carefully noted. Frequent borings were made over the entire project and samples were taken wherever there was any change in type or conditions. These samples were sent to the laboratory for analysis. The water holding capacity was determined for each of the types found, because it is an important factor in irrigation practice. The water holding capacity of a soil is determined by the size of its particles. The sandy types can hold the least water and the clays the most. All the water that a soil can hold is not available to plants. Every soil has a certain point beyond which the plants cannot draw water. This point is called the "wilting point." The water between the water holding capacity and the wilting point is the available water to plants. The amount of available water becomes larger as the water holding capacity increases: i. e., sand that has a water holding capacity of 20% has a wilting point of about 4% with 16% available water to plants. A soil with a water holding capacity of 35% has a wilting point of 10% with 25% available moisture to plants.

Soils that show a water holding capacity of 20%, by the test used in these investigations are considered very low in

water holding capacity. Such soils require frequent light irrigations, using a fairly heavy head in short furrows. Too heavy irrigations on these leachy soils wash out the available plant food. The water holding capacity is increased and the tendency to leach is decreased by maintaining an abundant supply of organic matter in such soils. Soils that show a water holding capacity of 30% to 35% by laboratory test have been found to be the easiest types to handle in irrigation farming, requiring only a few irrigations to maintain the moisture content of the soil for crop production. Leaching and organic matter content can also be easily controlled. Soils showing a water holding capacity of from 45% to 50% by laboratory test are too fine for the most successful irrigation because of the slow absorption of the water, causing water logging during the long irrigation period, which is harmful to plants. After irrigation the soil bakes so easily that it is difficult to maintain the necessary tilth.

In the physical analysis the soil particles were separated into groups according to the following table:

Type of Soil	Diameter of Soil Particles
Coarse gravel	2 mm.* and over
Fine gravel	1 to 2 mm.
Coarse sand	.5 to 1 mm.
Medium sand	.25 to .5 mm.
Fine sand	.1 to .25 mm.
Very fine sand	.07 to .1 mm.
Silt and clay	.0 to .07 mm.

*25 millimeters (mm.) equals one inch.

The above grouping is the same as that employed by the United States Bureau of Soils. The different types of soils as gravel, fine sand and loam are determined by the proportionate amounts of these different separates found in a soil by the physical analysis. Referring to the types given on the map a gravel soil contains more than 25% of coarse (2 mm.+) and fine gravel (1 to 2 mm.) and 20% of coarse sand (.5 to 1 mm.).

A fine sand contains more than 40% of fine sand (.1 to .25mm.). A loam contains about 40% of silt (.005 to .07) 20% of clay (.0 to .005 mm.) and the balance a mixture of the sands. A silt loam contains about 60% of silt, (.005 to .07 mm.) about 20% of clay (.0 to .005 mm.) and 20% of the finer grade of sands.

DESCRIPTION AND ANALYSIS OF THE SOIL AREAS OF THE PALOUSE PROJECT

Area I.

Area I. comprises those parts of the Project that are above the silt loam of Area V., and the beginning of the Big Bend wheat soils. It contains approximatly 20,000 acres. The vegetation is also very similar to that found on the silt loam of Area V. The surface soil of this area contains a larger portion of sand than the silt loam of Area V., due to the wind action, but underneath this drift soil it is of the same texture as Area V. The first two feet consist of fine sandy loam, while from the fourth to the seventh feet inclusive, it consists of a silt loam.

Table I., Mechanical Analysis of a Representative Sample of Soil of Area I.

Size of Soil Particles	Depth in Feet					
	1	2	3	4	5	6
Gravel........	.0%	.2%	.0%	.2%	1.5%	.1%
Fine Gravel...	.9%	1.0%	.7%	1.4%	1.9%	.9%
Coarse sand...	10.6%	9.1%	2.9%	3.8%	5.8%	3.4%
Medium sand.	17.6%	17.7%	8.8%	10.1%	11.1%	7.5%
Fine sand.....	48.1%	43.7%	24.9%	24.8%	26.4%	26.4%
Very fine sand	8.7%	8.8%	9.6%	10.3%	8.2%	8.5%
Silt and clay..	13.3%	18.9%	51.3%	47.8%	43.9%	50.2%

Water Holding Capacity
From 1 to 3 feet..............................27.0%
From 3 to 6 feet..............................30.1%

Chemical Analysis
Nitrogen, N .... .0170
Phosphorus, P_2O_5 .... .1700
Calcium, CaO 1.0050
Potassium, K_2O .... .1300

Area II.

Area II. is a large flat lying close to the Columbia River, covering about 6870 acres. It is covered mostly with sage brush, Festuca pacifica Piper, and an occasional grease wood bush. The surface soil is from two to four feet deep, having a large proportion of silty material mixed with medium sand. Under this surface soil is the same coarse black sand found under the fine sandy loam of Area IV. The difference between this Area and Area IV. is that the surface soil is deeper and is mixed with more of the coarser sands.

Table II., Mechanical Analysis of a Representative Sample of Area II.

Size of Soil Particles	Depth in Feet						
	1	2	3	4	5	6	7
Gravel........	.7%	.0%	.0%	.8%	.8%	2.0%	.0%
Fine Gravel...	9.5%	8.4%	6.8%	12.9%	20.6%	30.3%	
Coarse sand...	14.6%	12.5%	11.4%	18.5%	31.0%	38.0%	.9%
Medium sand.	2.5%	1.4%	1.7%	1.4%	3.6%	2.9%	1.9%
Fine sand......	20.4%	14.4%	14.5%	9.7%	7.8%	5.0%	21.5%
Very fine sand	18.8%	11.7%	13.7%	6.9%	4.6%	2.5%	19.9%
Silt and clay..	32.8%	51.0%	60.7%	49.0%	31.4%	18.8%	60.2%

Water Holding Capacity
From 1 to 3 feet 20.2%
From 3 to 7 feet 22.0%

Chemical Analysis
Nitrogen, N .... .0151
Phosphorus, P_2O_5 .... .1983
Calcium, CaO .... .6700
Potassium, K_2O .... .9790

Area III.

Area III. extends from the bend of the Columbia at about Section 7, Township 9, Range 29, and spreads out toward the northeast, covering about 36,000 acres. The whole area is more or less rolling due to the drifting sand. The principal vegetation is small sage brush. The soil is a coarse blue-black sand mixed with varying proportions of the fine sandy loam of Area I. The boundary between Areas III. and IV. is marked by an abrupt rise of several feet. This rise in Area III. gives the wind a good chance to act upon it; and like all wind-formed soils, the surface is rolling, and the texture becomes finer with the distance from the starting point of the blowing soil. This causes the soils of the southwesterly portion to be rather coarse in texture and those in the northeast portion relatively finer in texture.

The depth of the drifts vary from a few inches to many feet.

Table III., Mechanical Analysis of a Representative Sample of Area III., Taken from the Westerly Portion of the Area.

Size of Soil Particles	Depth in Feet					
	1	2	3	4	5	6
Gravel................	.2%	.3%	.1%	.0%	.0%	.0%
Fine Gravel...........	1.7%	2.1%	1.2%	.3%	.2%	.2%
Coarse sand...........	17.8%	29.6%	29.1%	48.6%	31.5%	11.6%
Medium sand..........	18.6%	9.5%	26.3%	26.3%	43 5%	35.9%
Fine sand.............	42.5%	38.6%	30.6%	18.8%	22.6%	49.4%
Very fine sand........	7.1%	7.1%	4.6%	2.1%	1.4%	1.0%
Silt and clay..........	11.9%	12.2%	7.3%	3.3%	1.9%	1.4%

Water Holding Capacity
From 1 to 3 feet 22.7%
From 3 to 6 feet 26.0%

Chemical Analysis
Nitrogen, N .... .0095
Phosphorus, P_2O_5 .... .1403
Calcium, CaO .... .5180
Potassium, K_2O .... .1450

Taken from the easterly portion of the same area.

Size of Soil Particles	Depth in Feet						
	1	2	3	4	5	6	7
Gravel........	.0%	.0%	.0%	.0%	.0%	.0%	.0%
Fine Gravel...	.7%	.4%	.5%	.1%	.1%	.0%	.1%
Coarse sand...	6.3%	7.9%	3.8%	1.3%	1.3%	.1%	.8%
Medium sand.	18.8%	14.4%	11.9%	6.9%	8.5%	1.4%	6.2%
Fine sand.....	39.9%	39.9%	46.8%	17.7%	37.4%	9.2%	17.8%
Very fine sand	10.7%	13.4%	14.7%	16.2%	15.3%	16.3%	11.1%
Silt and clay..	22.5%	22.5%	21.5%	54.9%	37.6%	71.5%	62.3%

Water Holding Capacity
From 1 to 3 feet 24.5%
From 3 to 7 feet 30.8%

Chemical Analysis
Nitrogen, N .... .0107
Phosphorus, P_2O_5 .... .1733
Calcium, CaO .... .6330
Potassium, K_2O .... .3410

The analysis of these two samples of soil in the same area show that the texture becomes finer and the soil much richer in the essential plant food elements the greater distance from the starting point of the blow.

Area IV.

Area IV. is a rather level flat extending along the Columbia River, varying from one to two miles in width, and covering about 8550 acres. The principal vegetation growing upon this area is a short grass known as Festucia pacifica Piper, and occasionally a small sage brush.

The soil is a fine sandy loam which has been carried from the Horse Heaven country by the prevailing westerly winds. This soil varies in depth from one to three feet, and is underlaid by the coarse black sand.

Table IV., Mechanical Analysis of a Representative Sample of Area IV.

Size of Soil Particles	Depth in Feet			
	1	2	3	4
Gravel	2.5%	7.6%	13.6%	1.5%
Fine gravel	2.1%	1.9%	2.2%	3.1%
Coarse sand	2.9%	1.8%	3.9%	2.9%
Medium sand	2.5%	3.8%	4.2%	5.1%
Fine sand	27.7%	23.0%	20.8%	22.9%
Very fine sand	18.9%	18.2%	15.1%	18.7%
Silt and clay	42.2%	42.9%	39.5%	45.2%

Water holding capacity 26.4%

Chemical Analysis

Nitrogen, N .... .0189

Phosphorus, P_2O_5 .... .1893

Calcium, CaO .... .9860

Potassium, K_2O .... .2040

Area V.

Area V. is at an elevation just above Area VI. and contains about 25,430 acres. It is covered with sage brush, some grease wood and an abundant growth of bunch grass. This bunch grass is not found on any of the previously mentioned soil areas. This area can be quite easily located in the Project by this growth of bunch grass.

The soil is light colored and very silty in nature. It is rather hard and firmly laid down, and therefore resists the action of the wind and water more than the other types mentioned. The evidence of this resistance to wind action can be seen where this formation comes down to the Snake River and forms the climaxes of many knolls. Analysis shows this soil to have a finer texture than the previous types mentioned, and to contain a greater abundance of plant food elements.

Table V., Mechanical Analysis of a Representative Sample of Soil from Area V.

Size of Soil Particles	Average of 7 ft. in depth
Gravel	.0%
Fine Gravel	.4%
Coarse sand	3.8%
Medium sand	11.2%
Fine sand	23.3%
Very fine sand	8.2%
Silt and clay	51.8%

Water holding capacity 37.2%

Chemical Analysis

Nitrogen, N .... .0220

Phosphorus, P_2O_5 .... .1722

Calcium, CaO .... .5500

Potassium, K_2O 1.3200

Area VI.

Area VI. contains about 8650 acres and is generally found along old water courses. The vegetation is sage brush, Festucia pacifica, and an occasional grease wood bush. The surface soil is a fine sandy loam from one to two feet in depth, overlying a cemented mixture of shot gravel and ashy material. This surface soil has some of the shot gravel mixed with it, which was probably incorporated when the surface soil was deposited upon this formation.

Table VI., Mechanical Analysis of a Representative Sample of Soil from Area VI.

Size of Soil Particles	Depth in Feet			
	1	2	3	4
Gravel	5.3%	10.6%	53.4%	63.8%
Fine gravel	10.3%	4.3%	18.5%	11.4%
Coarse sand	3.6%	3.0%	9.8%	13.6%
Medium sand	12.8%	11.3%	8.0%	7.7%
Fine sand	48.8%	41.8%	8.1%	3.1%
Very fine sand	12.3%	13.2%	3.2%	.0%
Silt and clay	19.7%	15.4%	.7%	5.1%

Water Holding Capacity
From 1 to 3 feet 19.3%

Chemical Analysis
Nitrogen, N .... .0113
Phosphorus, P_2O_5 .... .2900
Calcium, CaO .... .9050
Potassium, K_2O .... .4960

Area VII.

Area VII. lies in the old water course of the higher elevations, and contains approximately 800 acres. The soil which is deposited in these old river beds has been washed down from the silt loam formation thru which they go, making it a very fine texture. The analysis shows it to be a silt and clay loam. There is an abundance of Tumbling (Jim Hill) mustard **Sisymbrium altissimum L.** growing on this area which was not found on any of the previous types.

Table VII., Mechanical Analysis of a Representative Sample of Soil from Area VII.

Size of Soil Particles	Depth in feet	
	1	4
Gravel	0.	0.
Fine gravel	0.	0.
Coarse sand	0.	0.
Medium sand	0.	1.3
Fine sand	0.	4.7
Very fine sand	14.2	7.4
Silt and clay	84.2	86.4

Water holding capacity 36%

Chemical Analysis

Nitrogen, N .... .0151

Phsphorus, P_2O_5 .... .1545

Calcium, CaO .... .9000

Potassium, K_2O .... .1450

Table VIII., Summary of the Water Holding Capacity and Chemical Analysis of the Different Areas.

Areas Type of Soil	Water Holding Capacity	Nitrogen N	Phosphorus P_2O_5	Calcium CaO	Potassium K_2O
I.—Fine sandy loam..	26.4%	.0189%	.1893%	.986%	.204%
II.—Medium sand....	24 0%	.0095%	.1403%	.518%	.145%
II. E.—Fine sand......	27.5%	.0107%	.1733%	.633%	.341%
III.—Sandy silt loam..	21.1%	.0151%	.1983%	.670%	.979%
IV.—Gravel..........	19.3%	.0113%	.2900%	.905%	.496%
V.—Silt loam........	37.2%	.0220%	.1722%	.550%	1.320%
VI.—Fine sand to silt loam............	28.5%	.0170%	.1700%	1.005%	.130%
VII.—Silt and,clay,loam	36.0%	.0151%	.1545%	.900%	.145%

Professor Maerker, Halle Station, Germany, gives the following percentages of the different plant food elements in a normal soil:

Nitrogen .... .10— .15%

Phosphcrus .... .10— .15%

Calcium,

Clay soil .... .25— .50%

Sandy soil .... .10— .20%

Potassium .... .15— .25%

The above table gives the percentages of the four essential plant food elements in the different areas. If we compare the analyses for the above areas with that of a good soil we find that phosphorus, calcium and potash are sufficient for good crop production. But if we compare the nitrogen we find that the soils of this entire project are deficient in this element. Phosphorus, calcium and potash are present, because they are a part of the original rock from which the soil is formed and are lost only by drainage or cropping, but nitorgen is obtained from decaying organic matter and the air, and lost principally thru drainage, and cropping, and under certain conditions thru gaseous escape into the air. All arid soils decompose organic matter rapidly and consequently are low in this constituent and nitrogen. In order to increase the nitrogen content it is necessary to add some organic material either thru barnyard manure or by plowing under some green crop.

AREA CHARACTERISTICS

Leveling

Areas I., II., IV. and VII. are comparatively level, requir-

ing very little work to get them in shape for irrigation. Areas III. and VI. are rolling and will be difficult to get ready for water.

Irrigation

It will not be very difficult to irrigate Areas I., V. and VI. because of the large amount of fine particles mixed with the sand. Areas II. and IV. will require much attention in applying the water, and Area III. will be exceedingly difficult to irrigate by the furrow method, because of the coarseness of the soil. Area VI. will be hard to handle, because of the cemented nature of the subsoil layer.

Tillage

The whole project is very easily tilled.

Fertility

The fine brown sand that blows across the Columbia River and is mixed with the different types of the whole project, is very well supplied with all the elements of plant food. The surface soil of Area IV. is made up entirely of this sand. Area III. is a mixture of this sand and the blue-black sand that underlies the whole project. This blue-black sand is very low in the available plant food elements, because of the small surface area exposed to the action of the roots and soil moisture. Area II. contains more fine sand than Area III., therefore is a better soil. Areas V., I. and VII. are mixtures of the brown fine sand and the original silt loam of Area V. These areas are the most fertile of the whole project and well adapted to irrigation purposes. As far as clearing the land, choice of crops and susceptibility of frosts are concerned, one area is about the same as the other.

AGRICULTURAL VALUE

The location of this project in relation to markets is very favorable. It has a water way down the Columbia River to Portland and the ocean. The Spokane, Portland and Seattle railroad following the banks of the same river also runs into Portland. The Northern Pacific touches the leading Puget Sound cities: Seattle, Tacoma, Olympia, Everett, Bellingham, etc. From these cities the ocean may be easily reached. The Northern Pacific also runs east to Spokane and Walla Walla and on thru to the eastern markets. The Oregon-Washington Railroad and Navigation Company connecting with the Union Pacific is just across the river from the land in question.

At present a few homesteaders are trying to grow crops by dry farming methods, but without success. Intertilled crop as corn and potatoes make small growths. The cereals, as wheat, oats, etc., are usually grown only for hay.

The raw land is not difficult to improve. The sage brush is taken off by first cutting or breaking it off with some implement like a railroad rail, having a team hitched to each end, and dragging it crosswise over the land. The brush is then raked up with a horse rake and burned. After leveling, it is sown to rye in the fall. The following spring vetch or alfalfa is sown into the rye without disturbing the surface of the soil except to drill in the seed. This is done to protect the soil from blowing. The problems that trouble the farmers of other like-projects are, soil blowing, lack of humus and irregular surfaces. The best method of improving this soil is by plowing under some green legume crop as alfalfa, vetch, etc.

The mild climate and long growing season makes it possible to grow most of the important agricultural crops. The crops that are likely to be best adapted to this section are the tree fruits as peaches, cherries and early apples; the small bush fruits as strawberries, raspberries and grapes. Among the farm crops alfalfa, vetch, clover, rye and corn; the vegetables, potatoes, sugar beets, mangels, carrots, tomatoes, etc., are likely to be well suited to this project.

The principal crops grown in the Kennewick region, just across the Columbia River from this project are alfalfa, corn, potatoes, apples, cherries, peaches, strawberries and grapes.

In most of the irrigation projects the farmers have found that it is more profitable to raise some stock along with the orchard or farm crops. Dairying is becoming quite an industry in most irrigated sections. Alfalfa and corn are thus fed on the farm. In addition to dairying hogs, sheep and poultry are used to utilized waste products.

Alkali conditions are not serious in this project. All the soils are slightly alkaline but not sufficient as to interfere with crops. Because of the open nature of the soils and especially the good subsoil drainage, the alkali would not seem likely to concentrate at lower elevations and cause damage as in some of the other projects.

It has been found that soils best adapted to agriculture under irrigation is a fine sandy loam at least four or more feet deep. Practice has shown that it is difficult to keep enough water and organic material in a coarse textured soil for profitable crop production.

CLIMATE

The climate of this project is mild and dry. Thunder storms seldom occur and when they do, they are very light. Tornadoes never have been known in this state. The aver-

age rainfall for a series of years is 7 inches, falling principally in the winter and spring months. Very little of the precipitation falls as snow and when it does it remains on the ground only a few days. The air is very dry, seldom containing more than 40% of its moisture holding capacity. The average annual temperature is 53.2°.* The length of the growing season is 190 to 200 days, from April to October, inclusive, with an average temperature for this period of 65°. The average temperature for the different seasons of the year are as follows:

Winter—December, January and February, 33.9°.
Spring—March, April and May, 54.8°.
Summer—June, July and August, 71.5°.
Fall—September, October and November, 52.6°.

*Fahrenheit.

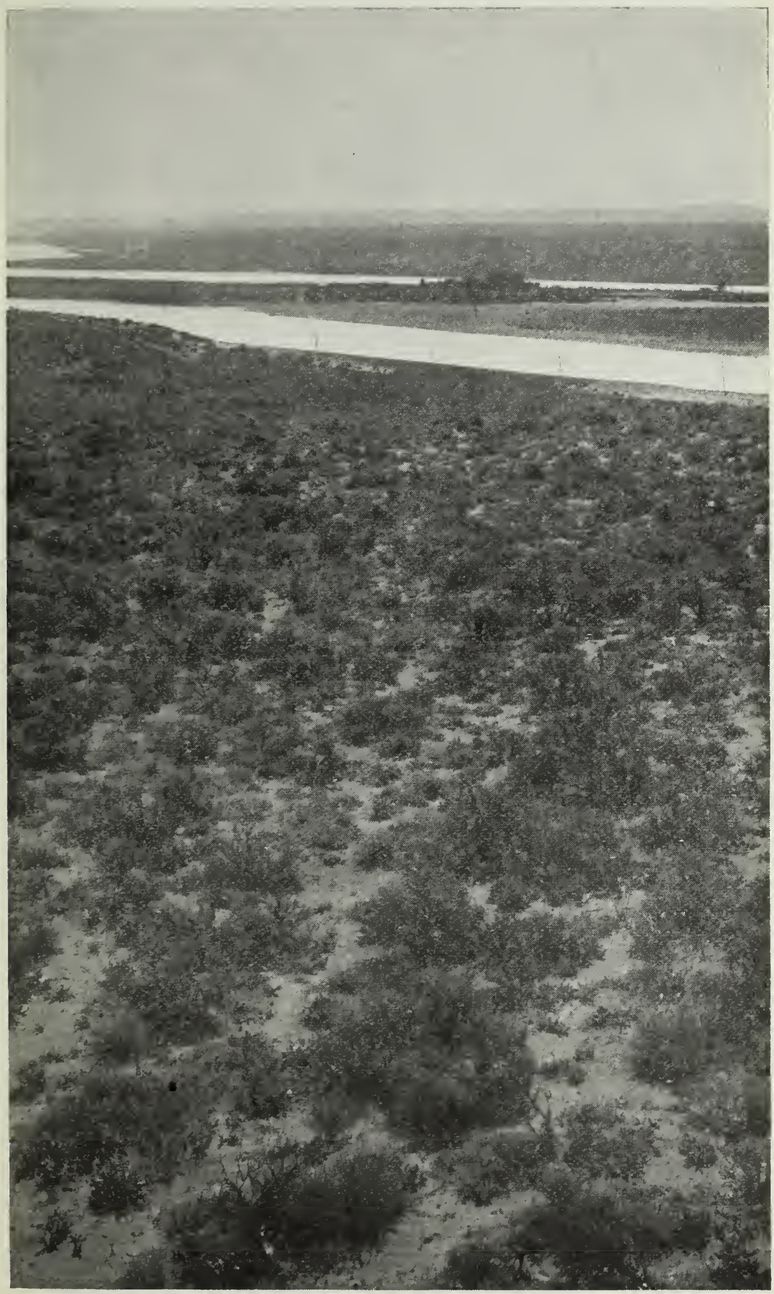


Fig. I.—Raw land covered with small sage brush. Columbia River in the distance.

Fig. II.—Showing methods of preparing land for irrigation.

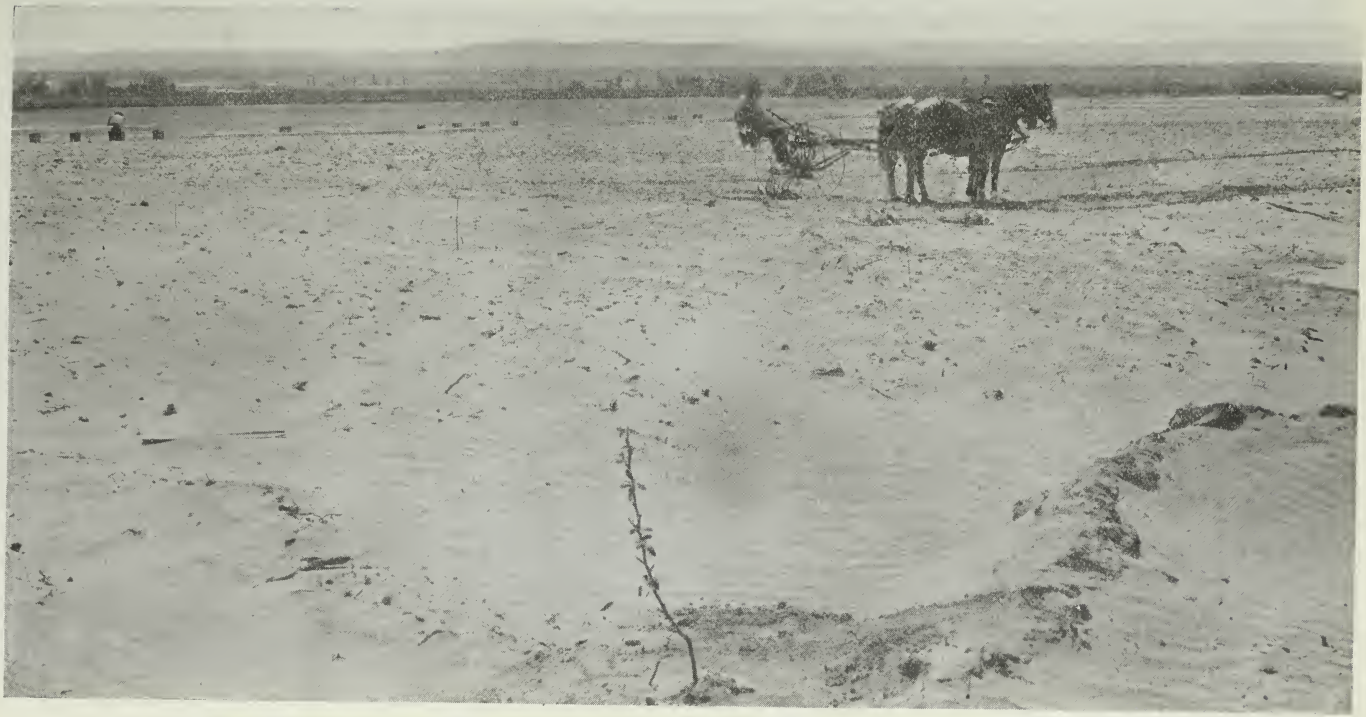


Fig. III.—Showing the leveled land ready for water. Building a flume in the distance.

Fig. IV.—Alfalfa growing between tree rows in a young orchard.

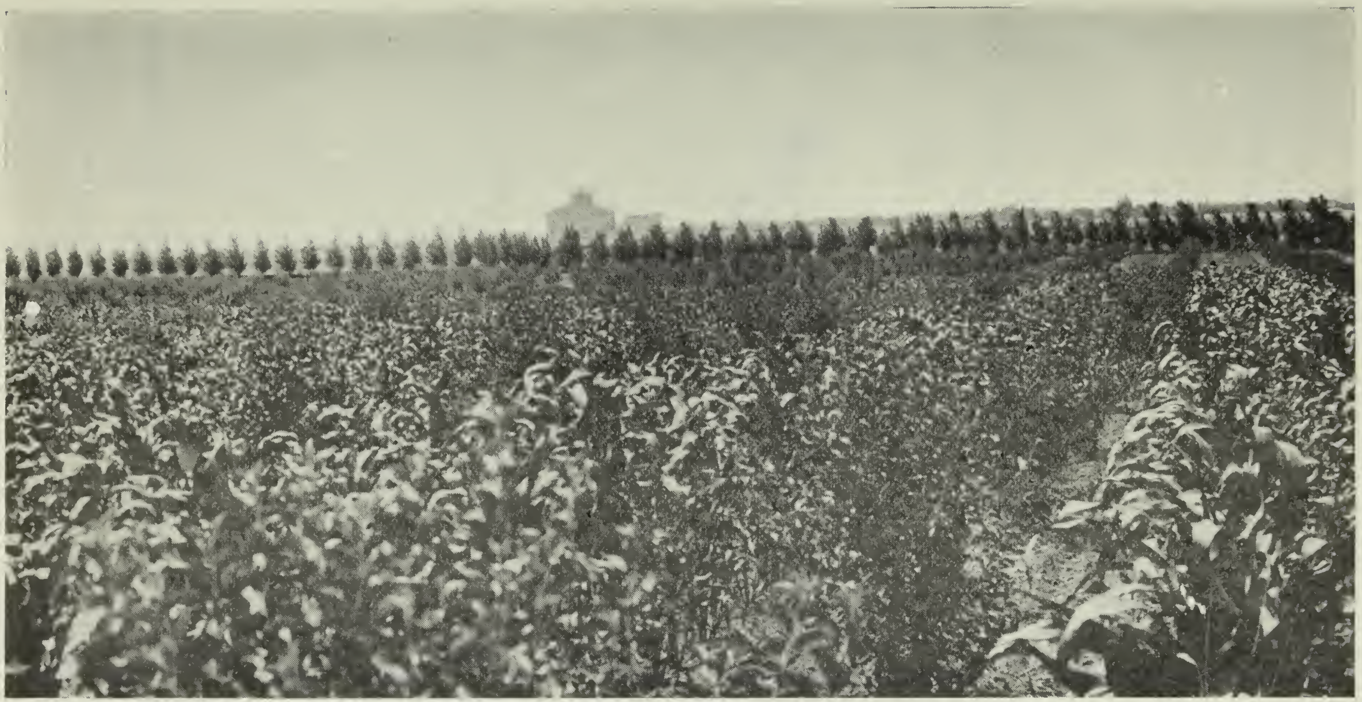


Fig. V.—Inter-cropping with corn and other crops

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON.

DIVISION OF AGRICULTURE
ANIMAL HUSBANDRY

Sheep Husbandry in the Pacific Northwest

By
WILLIAM HISLOP
and
C. E. HOWELL

BULLETIN NO. 134
January, 1917

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*Died August 18, 1916.

SHEEP HUSBANDRY IN THE PACIFIC NORTHWEST

By

William Hislop, Animal Husbandman
in the Experiment Station
and
C. E. Howell, Instructor in Animal Husbandry,
State College of Washington

The data presented in this bulletin have been gathered from a circular letter sent in April, 1916, to all the members of the Washington Wool Growers' Association. This organization embraces those who own several thousand sheep as well as those who possess a few hundred. The replies received represent all degrees of ownership. The questions were intimately connected with mutton and wool production under range conditions in the Pacific Northwest, and the answers provide trustworthy information as to actual range practice in the sheep industry.

Copy of Circular Letter

Gentlemen:

I shall be obliged if you will answer the following questions and return them in the enclosed envelope:

Questions:

1. How many ewes have you lambed this spring?
2. What per cent. of lambs have you saved?
3. What is the breeding of your ewes?
4. What breed or breeds of rams do you use?
5. Why do you prefer that breed or breeds?
6. How many ewes are placed with each ram?
7. Where is your summer range?
8. Where do you winter?
9. Where do you lamb?
10. What are the most common causes of death among lambs?
11. Where do you market your lambs?
12. When do you market your lambs?
13. What is the average weight of lambs when loaded to market?
14. What weight of fleece does your ewe flock shear?
15. Where do you market your wool?
16. What does it cost you to run one ewe for one year?
17. How long before shipping to market do you wean the lambs?
18. What feeds do you use for wintering the ewes?

Thanking you in anticipation, I am

Yours very truly,

WILLIAM HISLOP, Animal Husbandman.

Scope of the Inquiry

The answers which were received represent a total of 201,010 head of ewes. This number is approximately one-half that of the present sheep population of the State of Washington.

Breeds of Ewes on the Range

About 85% of the 201,010 ewes examined have a foundation of Merino blood. Many owners have adopted the Rambouillet type, while others use the Delaine type of Merino.

Fig. 1. Lincoln Ewes on pasture in Yakima Valley, Washington.

The replies showed that 14.3% of the ewe flocks were Lincolns. One band of 10,000 head, contained an equal number of Shropshire and Cotswold ewes.

Breeds of Rams on the Range

The data obtained throw light on the much discussed question as to which is the most extensively employed breed of rams for the range. Thirty-two and six-tenths per cent. of the men answering the inquiries are using Shropshire rams; 44.2% are using Lincoln rams; 23.09% are using Hampshire rams, and 7.6% are using Rambouillet rams. One man is using Oxford rams on his band of ewes; two men are using

Fig. 2. Registered range Rambouillet rams. Note strong character and bone. (McGregor).

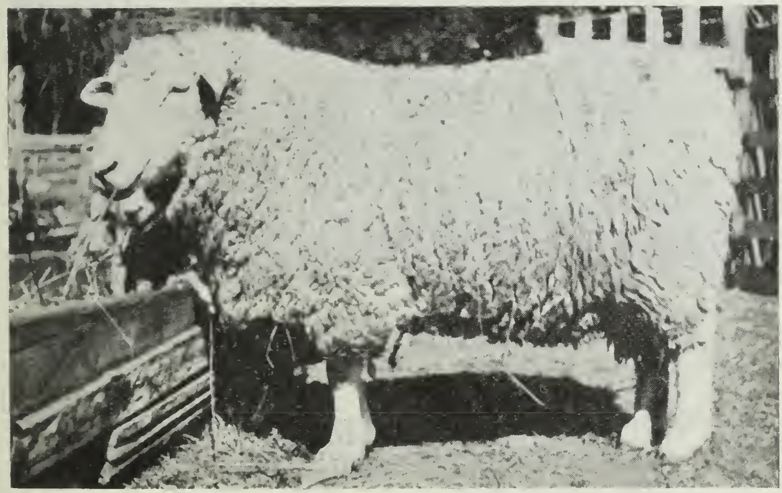

Fig. 3. An imported Romney ram owned by H. S. Coffin. Note the bone and masculinity.

Cotswold rams; two are using Delaine rams, and one is using Corriedales.

Some Reasons Given in Favor of Different Breeds of Rams

Shropshires: They are preferred because "The lambs are better for early market"; "They are easily fattened"; "They mature early and produce good quality of mutton"; "They produce early mutton lambs"; "They mature quicker and are better sellers."

Lincolns: "They give more wool and produce bigger lambs"; "They yield the best combination of wool and mutton"; "They are good rustlers"; "They are in good demand"; "Their lambs mature early"; "We use Lincolns for size"; "Produce higher priced wool."

Hampshires: "To get the big, fat lamb"; "They fatten quickly and are the heaviest on July 1st"; "Packers like them

Fig. 4. Range scene in Cascade Mountains in Washington. (Benson). Cross-bred Hampshire X Shropshire lambs. Age 4 months. Weight, 60 to 80 pounds.

best"; "Most buyers prefer a black faced lamb for a feeder"; "When crossed upon half bloods they get early maturing lambs that are good feeders."

The more extensive use of the Lincoln as compared with the Shropshire is due to the fact that many of the flocks investigated are in close proximity to the Willamette Valley. It is in this section of the State of Oregon that Lincolns are produced which equal those bred in any part of the world.

Number of Ewes with Ram

The average number of ewes to one ram is 65. Some owners are running as few as 30 ewes with one ram, while others are allowing as high as 80 to 100 ewes to run with one ram. The numbers vary accordingly to the way in which the ram is managed and the nature of the country. Rams that are allowed to run in the band without rest or feed should not be allowed to serve more than 50 ewes. If they are taken from the band during the day and are turned in again at night they can serve a much larger number of ewes (75 to 80) during the season.

The Lambing Percentage

The percentage of lambs varied from 70 to 130. The average of the 201 010 ewes is 92.32%. This is considered to be low by most sheepmen. A number of reasons were given as to the cause of the low per cent. for the 1916 lamb-

Fig. 5. Romneys on H. S. Cofftn's Mountain Vale Ranch

crop. It was a very severe winter in some sections and the ewes came thru in rather thin condition. The snow was exceptionally heavy and a number of sheep sheds were broken down, thereby exposing the ewes to adverse conditions.

Time of Weaning the Lambs

It is not a general practice among sheepmen to wean lambs before shipping. They are taken direct from their mothers and shipped to market. Those men who hold their lambs over until they are yearlings usually wean them in October.

Time of Marketing Lambs

The great majority of the lambs bred in the Northwest are not shipped to market until September, 35% being shipped during this month. Twenty-five per cent. are shipped in July; 20% in August, and 20% are held until October. These percentages represent the conditions as they actually exist at the large Middle Western markets. The early lambs are shipped eastward in July, but the great bulk of range lambs go East during the early fall to supply the feeder market.

Weight of Lambs at Time of Marketing

The weight of the range lambs when they reach the market varies from sixty to eighty-five pounds. The average of the figures received is seventy-three and one-half pounds. This weight fully satisfies the packer's demands.

Fig. 6. These cross-bred Rambouillet X Shropshire lambs owned by McGregor weighed 78 pounds in Chicago at 4½ months old.

A lamb weighing around seventy-five pounds is much more desirable than one weighing ninety to one hundred pounds. Range lambs at the former weight when well finished more often top the market than native lambs. Quite frequently the native lambs are too heavy to bring the top prices.

Due to the fact that in some sections of the country grazing land is very cheap and feed plentiful some owners hold their lambs over and sell them as yearlings. By so doing they get one clip of wool from the yearling sheep before

selling. Such practice, however, is becoming less frequent each year.

The Lamb Market

A large percentage of the lambs from the ranges are shipped direct to Chicago. Two or three men ship to Omaha. The bulk of the lamb crop is sold at home to commission men or to large business firms which ship them to Portland or Seattle, or send them to the eastern markets.

Fig. 7. Yearling Rambouillet wethers. Few yearlings are found on the range no./-a-days. (McGregor).

Weight of Wool Clip

The average weight of the fleece varies from 7 to 11 pounds. The average of the 201,010 ewes is 9.5 pounds. This is an exceptionally high average when one considers that a large number of the range sheep are grades. It is due, no doubt, to the high percentage of Merino blood which exists in the range flocks, and to the use of rams of the improved breeds.

The Wool Market

Most of the wool clip is sold on the ranges to commission men who collect it into large consignments and ship to Boston, or Philadelphia. Several growers who produce large clips ship direct to Boston.

Cause of Death in Range Sheep

There are a number of interesting facts and conditions brought out in the answers, which could not be presented in

Fig. 8. The sheep are shown here moving to another camp. Parts of this trail are very rough and pack horses find difficulty in going over it. (Fig. 3, Gen. Bul. No. 122, Wash. Sta.).

tabulated form. Many and varied were the reasons given as to the causes of death among the sheep. The greatest complaint is registered against poisonous plants and coyotes. About as heavy a toll is taken by these two elements as from all other sources combined. One of the water lillies and death-camas (*Zigadenus veneous*) are the two most common weeds that poison sheep. The coyote, wild cat and bear kill a large number every year. These wild animals do most of their damage to flocks grazing on the large ranges, especially in the Ranier National Forest and the Wenatchee Forest Reserve.

On some of the ranges the sheep are not properly sheltered and many die from exposure to cold and rain. Lack of attention at lambing time thru shiftless herders is often the source of heavy losses in both the ewe flock and the lamb crop. From some sections comes the complaint that the lack of early grass prevents the ewe from properly nourishing her lamb.

Disease in the flock is very uncommon in the Pacific Northwest. Only one man reported a loss due to worms and one lost a few head from black-leg. Some owners suffered a loss in their lamb crop from scours, no doubt caused by careless feeding or possibly navel infection.

Kind of Feeds Used

Alfalfa hay is used almost exclusively as the roughage portion of the sheep's ration. In some sections alfalfa hay can be secured at a very low cost. Where it is grown abundantly it can be obtained for from $6.00 to $8.00 per ton. These prices are not uncommon except in periods of scarcity like the past winter where in some localities it sold at $20 per ton. Oat and wheat hay are also used quite extensively. The most common kind of grass found on the range is the bunch grass. It grows abundantly in most places and the sheep thrive on it.

Very little grain is fed except during the severe winter months. The grain ration consists of barley, wheat, oats, and corn. Where root crops such as carrots and mangels are available they are used to supplement the hay and grain ration. Silage is used in a very limited way, largely because sheepmen are as yet unfamiliar with it.

Cost of Keeping a Ewe One Year

The cost of keeping a ewe one year will necessarily show considerable variation. It will depend upon the amount and kind of grazing land, cost of grazing, cost of herding, amount

and kind of grain fed, the length of the feeding period during the winter, the price of feeds and their availability in that particular section of the country. One man, who has a band of 2,000 ewes, estimated that it cost him 75 cents a head to run his ewes for one year. This was the lowest estimate given. The highest was $5.00 a head. The average of all the estimates was $2.59.

Itemized Cost Accounts of Bands of Purebred and Grade Ewes.

A. 3000 Purebred Ewes on range in the Yakima Valley, Washington, obtained Jan. 1st, 1915, from books of owners.

	Ten Year Average Per head	Total
Labor (shearing, bags, twine, storage, insurance, haulage)	$2.07	$ 6,206.00
Groceries or supplies	.58	1,750.00
Outfit, tent, cooking utensils	.18	554.00
Range and pasture	.52	1,558.00
Hay and grain	.65	1,942.00
General expenses	.30	899.00
Advertising, taxes, selling	.11	324.00
Loss of 5% of ewes valued @ $7.00 per head	.35	1,050.00
Grand total		$14,283.00

Average cost per year per head $4.76
Per cent lambs, 130.

These pure bred ewes can not be handled in large bands because they require more attention, hence the over-head investment is higher.

B. 2400 Grade Ewes, on range near Wenatchee, Washington; obtained Jan. 1st, 1915, from owners.

	10 Year Average per Head
Range	$ .30
Hay	.30
Wages	.65
Supplies	.30
Taxes	.06
Interest on principal and running expenses up to and after shearing	.56
Loss of sheep 5%	.26
Incidental expenses	.12
Risk	.10
Deterioration in value with age	.30
Bucks	.29
Buck pasture	.07
Shearing, bags, twine, hauling, storage, insurance	.17
Average cost per head per year	$3.48

Per cent lambs, 115.
Buying price of yearling ewes, $5.00 to $7.00 per head.
Selling price of six-year-old ewes, $3.50 to $4.00 per head.
Hay, $6.00 per ton.

Average hay ration per day in winter, 3 pounds.
Average feeding time per year, 30 days.
Bucks, $20.00 per head for yearlings.
Sale price for bucks at 6 to 7 years, $0.00.

Some sheepmen raise their own hay. Some raise their own breeding ewes. Some raise their own bucks. Some have their own buck pasture, while others do not. Some have better range than others. They can thereby cut this expense still further.

SUMMARY

The following table gives a detailed presentation of the data compiled from the replies received. It sets forth the facts as stated by the individual sheepmen.

No. of ewes	Percent lambs	Breeds of ewes	Breeds of rams	No. ewes with one ram	Time of marketing Lambs	Av. wt. lambs at mktg., lbs.	Av. wt. wool clip lbs.	Cost of keeping a ewe one year
1,185	130	Grade Lincoln	Shropshire	80	July 1	67	7	$2.50-3.00
3,000	92	Rambouillet	Rambouillet	45	....	..	10	2.00-3.00
2,050	99	Merino	Lincoln	70	September 15	70	9	3.50
2,500	100	Lincoln	Shropshire	75	July 1	..	8	2.50
3,400	94	Rambouillet	Hampshire	75	September 1	75	11	3.00
2,200	90	Grade Lincoln	Shropshire	75	....	72	7	3.50
10,000	90	Merino	Lincoln & Hamp.	50	September 1	70	8	3.00-4.00
3,700	99	Merino	Shropshire	75	September 1	75	9	3.50-4.00
3,700	80	Lincoln	Lincoln	75	July 15	70	...	1.50
4,800	95	Merino	Hampshire	60	October 1	78	9	3.00
2,700	88	Rambouillet	Oxford	70	September 1	75	10	....
3,700	100	Rambouillet	Lincoln	80	August 25	85	9	2.50-3.00
2,200	84	Merino	Lincoln	90	August	73	10	2.50-3.00
1,800	85	Merino	Lincoln	60	September	75	11	2.00
7,500	105	½ blood Lincoln	Hampshire	75	August 1	75	9	3.00
3,600	94	Lincoln	Lincoln	70	....	82	10	2.65
2,600	100	Delaine	Delaine	50	September	..	8	2.50
1,150	95	Delaine	Lincoln	40	October 1	65	10	2.50

No. of ewes	Percent lambs	Breeds of ewes	Breeds of rams	No. ewes with one ram	Time of mar keting Lambs	Av. wt. lambs at mktg.,lbs.	Av. wt. wool clip lbs.	Cost of keeping a ewe one year
1,200	98	Rambouillet	Shropshire	50	October	73	12	....
1,800	94	Delaine	Lincoln	75	....	..	11	....
1,400	108	Merino	Shropshire	75	August	70	7	2.00
1,050	100	Lincoln	Shropshire	75	July	73	9	....
1,200	98	Merino	Hampshire	60	July 1-15	75	9	....
2,000	100	Rambouillet	Lincoln	65	September	75	12	.75
8,000	85	Merino	Lincoln	50	October 1-15	73	8	2.50
4,700	100	Merino	Lincoln	75	September 20	60	10	5.00
1,200	95	Merino	Shropshire	70	October 1	70	10	1.50-1.75
2,425	88	Rambouillet	Shropshire	85	July	68	9.5	3.60
1,400	70	Merino	Rambouillet	70	As yearlings	..	10	1.50
6,000	85	Merino	Lincoln	30	....	..	10	1.50
1,100	108	Lincoln & Delaine	Shropshire	75	September 1	80	10	2.00
3,800	83.	Merino	Cots. & Lincoln	60	August	74	12	2.00
3,000	80	Merino	Shropshire	80	September 1	78	9	3.00
10,000		Shrop. & Cots.	Shrop. & Cots.	50	August	64	7.5	3.00
3,200	75	Merino	Lincoln	60	As yearlings	..	10	3.25
3,000	95	B. & C. Merino	Shrop. Hamp. Cor.	60	July and August	75	7.5	....
3,000		Rambouillet	Lincoln & Hamp.	50	July	70	10	2.00
2,500	95	Merino	Shropshire	70	July	65	12	3.00
5,300	100	Rambouillet	Rambouillet	70	August 15	75	12	2.50
3,500	85	½ blood Lincoln	Lincoln	70	October 1	80	9	3.50
3,000	90	Rambouillet	Shropshire	75	September 30	75	11	2.00
2,500	70	Merino	Shrop. & Hamp.	75	September	..	7	3.50
1,800	100	Rambouillet	Rambouillet	60	As yearlings	..	9	2.00
2,900	84	Merino	Lincoln	..	September 1	70	10.5	3.00-3.20

No. of ewes	Percent lambs	Breeds of ewes	Breeds of rams	No. ewes with one ram	Time of marketing Lambs	Av. wt. lambs at mktg., lbs.	Av. wt. wool clip lbs.	Cost of keeping a ewe one year
9,250	85	Rambouillet	Shropshire	65	July	70	11	2.25
9,500	95	Ramb. & Hamp.	Hampshire	50	October	65	8	2.00
3,100	80	½ blood Lincoln	Lincoln	75	September 1	85	7	2.00
900	80	Delaine	Delaine	70	....	..	9	1.00-1.50
1,200	90	Merino	Lincoln	40	October	..	8	1.00
2,600	93	Rambouillet	Hamp. & Lincoln	70	September	80	9	3.50
30,000	90	Merino & Lincoln	Lincoln & Hamp.	65	August	80	12	3.50-4.00
1,700	97	Merino	Lincoln	65	As yearlings	..	11	....
201,010	92.32			65		73.5	9.5	2.59

*Explanation of contractions employed in the above table:

Shrop. equals Shropshire, Ramb. equals Rambouillet, Cots. equals Cotswold,
Hamp. equals Hampshire, Linc. equals Lincoln, Cor. or Corrie. equals Corriedale.

LETTERS RECEIVED FROM SHEEPMEN IN THE NORTHWEST

The personal element in them is of immense value to all who are interested in the industry. In this way light is cast upon many points not touched upon in the circular letter.

This letter outlines sheep management on the range.

"Dear Sir:

"As there was not space enough to explain myself fully, I will add a few remarks about range sheep. I keep my half-blood Lincoln ewes until they shear four fleeces. On the range where the country is not too rough to permit of proper herding, half-blood Lincolns shear more wool of better quality than any other half-blood sheep. The wool will outsell Merino wool by 5 to 7 cents per pound, Shropshire wool by 2 to 3 cents per pound and will shear 3 to 4 pounds more wool than a half-blood Shropshire. They are also great mothers. I bred 200 aged ewes to two- and four-year-old Lincoln bucks and had 94% of the ewes with lamb after the rams were with them for 38 days. My ewes came fat out of the mountains into the clover and stubble pastures where they were bred. Then I put them on the winter range on dry feed and fed the bucks grain and hay and only put them with the ewes at night. As a rule 75 to 85 ewes to one ram is the way most sheepmen breed on the range. Still a good ram well grained is good for 100 ewes in a small band on a farm or even on the range if properly handled.

"Respectfully yours,
(Signed) K. O. Kohler."

"P. S. My last year's wool was just sold in Boston for 22½ cents per pound last month. I was offered 17 cents for it here last spring. Freight is $1.55 per hundred and commission 1½ cents per pound."

The following letter relates experiences with poisonous plants on the range.

"Dear Sir:

"In answering your questions I am prompted to offer a little of my experience that may be of use to some of your correspondents. I have used the Colville Forest Reserve for three summers. First year we lost about 50 head of ewes and lambs from Poison Camas. Second year we did not lose a sheep from poison. Third (last summer) we lost about 150

Fig. 9. View of a mountain range and flock of Lincoln ewes owned by H. S. Coffin.

head, and my neighbor, Walter Kemp, who shipped with us, lost about two-thirds of his band on the very same ground where we staid with two bands during the first night after unloading, the year before, and we did not lose any that year. Yet ten days later, other parties passed over this same ground and lost 60 and 80 head respectively. The first year the feed was plentiful when we shipped in. Second year feed was quite young. Third (last year) feed was advanced and very abundant. The Death Camas was in full bloom. My advice to any one who uses a range infested with Death Camas is to go early while the forage is scant. Sheep are in the habit of running after flowers, and I believe that is the most poisonous stage. We had the worst time with poisoned sheep the day after unloading. But we had one band poisoned three and again six days later, and a few scattering ones a week later. We prepared hay to feed this year, when first unloading, but owing to a considerable rise in car-rates on the G. N. Ry. we have determined to go by trailing in through the south half of the Indian Reservation.

" Yours respectfully,

(Signed) "Willis Mercer."

This letter gives range sheep management, breed preferences and causes of death among lambs.

"Dear Sir:

"I am not in the sheep business at the present time, however, I will try to answer the questions you have asked. They appeal to me because I have been keeping myself fairly well posted on that line, expecting to re-enter the industry. I was with Mr. Leon Jaussand during lambing season this year. It was a very poor season on account of the hard winter thru which the sheep passed. The per cent of lambs was very low, about 75% where formerly the average was about 95% in this locality. Mr. Leon Jaussand lambed 3600 ewes with an average of 75%. His ewes are grade Rambouillets which, I think, are the most profitable sheep for the range, being good mothers, heavy shearers (12 pounds), banding well, steady feeders, and not being so hard on range as the coarser breeds. I prefer the Hampshire-Down rams to other breeds where the lamb crop is intended for the mutton market, because they get very strong, hearty lambs with a better average weight at time of marketing, being at least 5 pounds heavier than other breeds at the same age with the same care. I think where the rams are not tended and allowed to stay in the band without resting or feeding not more than 50 ewes to the ram should be allowed. I prefer to take rams

from the flock during the day to rest and feed them, returning at night. In that way I can safely place a greater number of ewes to the ram (75 to 100).

"My summer range is in the Wenaha Forest Reserve, Oregon. My winter range is on the breaks of Snake River near its mouth. I lamb on my winter range. The most frequent cause of death to lambs is a hard question to answer because there are so many causes of death from the time of birth to the time of marketing. However, I will try to name some of them. (1) The feeding of salt in troughs placed too high for lambs to conveniently reach causes them to eat too much dirt by licking the ground under or near the trough. (2) By not keeping salt in the troughs constantly, thereby causing the mothers to rush to the troughs and jamming the

Fig. 10. Sheep gathered on bedding ground, settling down for the night. The meadow has not been cultivated and is in its natural state. (Plate I. Fig. 1, Gen. Bul. No. 113, Wash. Sta.).

lambs against the troughs. (3) By using the dogs too roughly thereby making the mothers jump on the lambs and inflicting great injury to lambs. In that way inflammation of the liver and bowels sets in because they are too young to stand such harsh treatment. (4) In summer time the loss on the range is heavy by lambs eating too great an amount of salt, thereby causing stiffness. This stiffness is usually believed by sheepmen to be caused by their lambs eating

some poison weed or fungus growth. By experimenting to find what caused that stiffness, I came to the conclusion that it was caused by the lambs eating too great an amount of salt at one time. Older sheep are not affected with the stiffness. I began to use one pint of turpentine to each 50 pounds of salt that I fed to my sheep and from that time I was not bothered with stiffness in my lambs and the loss occurring from salt eating.

"Respectfully yours,
(Signed) "Frank Dickerson."

This letter gives the cost accounting of one ewe for one year together with a system of winter feeding and the management of ewes at lambing time.

"Dear Sir:

"I figure the cost of $5.00 for running a ewe for one year, as follows: 1200 ewes:

Herder and his grub	$600.00
Camp tender	250.00
1 foreman, lambing 1½ months	90.00
1 nightman, 30 days	45.00
3 men for 30 days	150.00
2 men for 20 days	60.00
Shearing and grub	300.00
Interest on flock of ewes, 1200 ewes @ $6.00 @ 8%	576.00
Taxes	50.00
Salt	50.00
Loss, 5% in y ar	300.00
Bucks to breed ewes	100.00
	$2571.00

"If one has his own allottment the summer fees are $72.00. If private range is rented one will be compelled to use 5 acres per head or 6000 acres at 10 cents or $600.00. Now, I figure that one can average the holdings of say 20 sheepmen and find that they have $25.00 invested for each ewe they own or $2.00 interest. I know that the board or tariff makes no allowance for your holdings, but that is not correct. Then there are always expenses unseen, and by the time on adds one's hay bill and grain bill the cost for running a ewe will be never under $4.50 and over a five-year run it will be $5.00. Now, this means to raise the lamb and sell it in the fall.

"Formerly we used to figure wear and tear at 25 cents. Today one cannot figure it at less than 50 cents per head. No two ranges are situated just alike, but where one has good range and an average climate I would say that 50 to 60 days

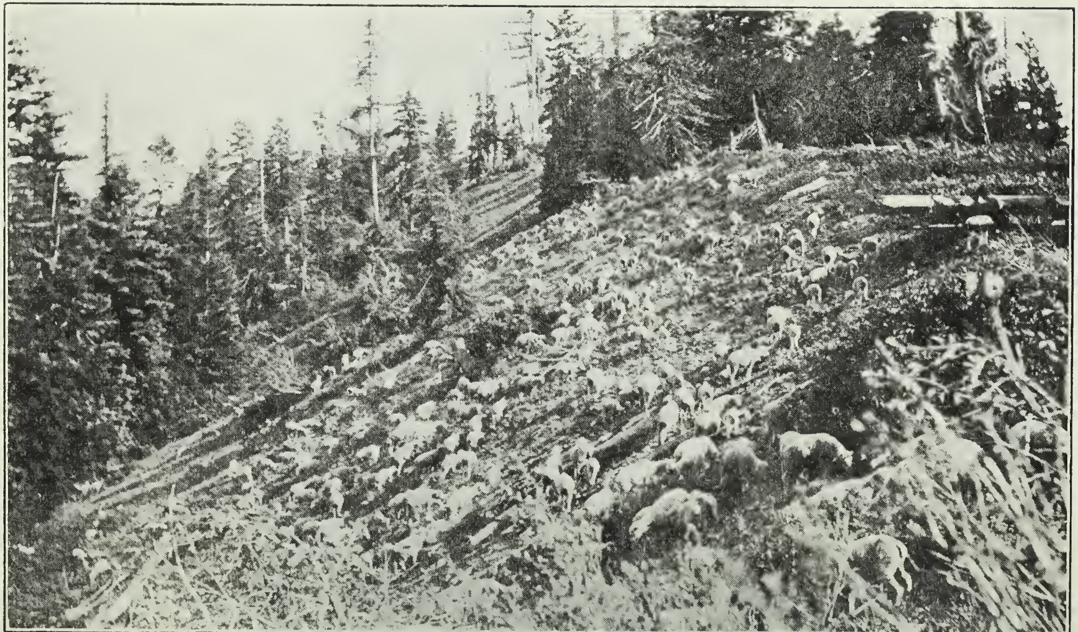

Fig. 11. Browsing on a steep slope in the Wenaha National Forest. (From Fig. 7, Gen. Bul. No. 122, Wash. Exp. Sta.).

feed would be required. I am a great believer in grazing in winter if the hills are not covered with snow. By taking sheep to the hills during the day and bringing them in at night one's sheep will winter fine on 1 to 1½ pounds of hay per day, but that hay must be fed at night and must be out when they come in from the hills. The days are then short, and this small feed will tide them over. Of course, as the season advances the hay will be increased. Just before lambing season if conditions will permit I feed considerable oats.

"If one runs Merino or Delaine ewes I prefer April lambs for this section of the country. If coarse wooled ewes are

Fig. 12. A typical sheep bridge in the Wenatchee Forest. Built of a fallen tree with poles nailed on the side. Will be swept out at first high water. This one is over White River above Lake Wenatchee. A permanent bridge has now taken its place.

handled one can lamb them in February and March, as they adapt themselves to hay better than the fine wools.

"I raise all kinds of hay, but my favorite feed is alfalfa mornings and wheat hay nights, that is, when on solid feed. I figure that in getting the exact cost one should figure just as tho one were to go to the market "broke" and had to buy everything the same as the merchant. One's money is worth the interest no matter if in land

"Yours truly,
(Signed) "C. A. Morris."

This letter gives observations of one who is closely associated with sheepmen and the sheep industry.

"Dear Sir:

"I do not own any sheep so many of your questions do not apply, but I can give you some information about the summer range and I can send you a list of sheepmen using the Wenatchee Forest if you desire it.

"Some 250,000 head of sheep, counting lambs, find summer range on this forest from about June 1st to October 10th. Sheep are entering the forest all the way from May 15th to July 15th and nearly all are out by October 10th. Lambs are usually turned off by August 15th. Owners who have lambed early often begin to ship lambs by the latter part of June. Weights run from 65 pounds to 76 pounds, averaging 72 pounds. Probably the largest number go to Chicago, frequently full train loads being made up. Many, however, are sent to Seattle and Vancouver. Formerly Merino ewes were most frequently seen, but now ewes with Lincoln or Shropshire lambs are most often to be found.

"Poisonous plants usually take a toll of from 200 to 1000 head of sheep during each summer and generally most of these are lambs. Coyotes and bears get 200 to 300 during the summer.

"As nearly as I can estimate it costs well toward $1000 to summer a band of sheep of 1100 to 1200 head of ewes with their lambs in the mountains for four months. This includes labor, subsistence for laborers, salt, grazing fees and miscellaneous items.

"Very sincerely yours,
(Signed) "A. H. Sylvester.
Forest Supervisor."

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF AGRICULTURE
Farm Crops

Inheritance in Wheat, Barley and Oat Hybrids

By

E. F. GAINES

BULLETIN NO. 135
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Inheritance in Wheat, Barley and Oat Hybrids

By

E. F. GAINES

SUMMARY

The following characters segregate in the F_2 as simple allelomorphs in the hybrids under discussion:

Grain	Dominant	Recessive	Ratio
Wheat	beardless	bearded	1 : 2 : 1
Wheat	club head	long head	1 : 2 : 1
Barley	hooded	bearded	3 : 1
Barley	covered	bald	3 : 1
Barley	2-row	6-row	1 : 2 : 1
Oats	black	white	3 : 1

Characters which are produced by multiple factors, or which are irregular in inheritance are:

Red and white grain in wheat;

Spring and winter character in barley;

Tree and side panicle in oats;

Hulless and hulled character in oats.

The following grains were used as parents in making the hybrids:

Name	Washington Number
Wheat	
Brown's Glory	550
Goldendale Bluestem	512
Hybrid 143	590
Minnesota Bluestem 169	523
Red Bluestem	517
Turkey X Bluestem	538
Oats	
Black, C. I. 290	665
Black Tartarian	750
Canadian, C. I. 444	742
Chinese Hulless, C. I. 298	686
Large Hulless, C. I. 278	680

Palouse Wonder 748
Regenerated Swedish Select 738
Sixty Day, C. I. 165 661
Storm King 746

Barley

Beardless, Success 873
Nepal 875
Black 874
Excelsior 959
Hulless 871
Rice, C. I. 341 912
Tapp 957

Much of the present investigation is corroborative of published work in Europe and America. Other results, however, are also presented which may be summarized as follows:

1. In the bearded and beardless wheat crosses the F_1 is intermediate and may be segregated in the F_2. It was not possible to segregate the heterozygote of the bearded and hooded barley crosses. Enormous numbers carried into the F_3 failed to produce modified types of these factors.

2. Two different crosses of spring barleys produced winter plants in the F_2 in the ratio of 3 : 13.

3. One variety of white hulless oats produced black oats when crossed with white hulled varieties. Hullessness prevented the developmnet of color in the floral glume in the parent and in the hybrids of all the different crosses tested.

4. Side and tree oat crosses produced intermediate types that bred true in subsequent generations.

5. In crosses of hulled and hulless oats the percentage of hulled plants in the F_2 approaches a simple Mendelian recessive but there is great irregularity between the true hulless and heterozygous types with an excess of heterozygotes in most cases.

INTRODUCTION

There are a great many different varieties of wheat. Each geographical unit has one to three dominant varieties, and from few to many minor strains that are grown in restricted districts. In Washington there are at least fifty-three distinct varieties of wheat grown. This multiplicity of varieties or sorts is evident in less degree only, with barley and oats.

These varieties differ visibly by combinations of relatively few fundamental characters such as color and texture of grain and chaff, time required for maturing, shape of the infloresence and length of the awn borne by the floral glume. These characters can be analyzed genetically only by hybridizing varieties that differ and by studying the resulting progeny.

The ten characters which are discussed in the following pages are not readily affected by changed environmental conditions. Five apply to floral glume variations, three to the inflorescence as a whole, one to the color of the grain and one to the length of the growing period. Six wheat, seven barley, and nine oat varieties were used in the parentage of the hybrids. Wherever the proper combinations could be obtained, the standard commercial varieties of Washington were taken to make the hybrids.

The author wishes to acknowledge the encouragement and inspiration of R. W. Thatcher in the beginning of the work. H. B. Humphrey has also given many valuable suggestions for analyzing and tabulating the records of the hybrids. Alex. Carlyle, Cerealist at the time this work was started, did much in the way of outlining and planning the field technique and order of planting. Of the men who have assisted in the field and record work, especial mention should be made of Karl Sax and C. D. Gaines, who have been associated with the work during the past four harvests and have helped with the records during their entire undergraduate work. E. M. East and E. G. Schafer have criticised the manuscript and have offered many valuable suggestions on interpretation and presentation. The illustrations are from photographs taken by Miss Orilla Miner.

REVIEW OF LITERATURE

The field of plant-hybrids had been covered in such exhaustive detail by Kölreuter in 1761-1766 that Sachs (8) considered subsequent investigators were unable to add anything essential. That was before the days of Mendelism. Since then volumes have been written about plant-hybrids from view points of which Kölreuter had never dreamed. Much of this material has had to do with agricultural crops. Spillman (9) showed that differing characters in wheat recombined in definite ratios in suceeding generations after hybridization. Thus *Triticum vulgare* crossed on *T. compactum* gave a type in the first generation (F_1) intermediate in head-length, with a ratio of 1 *compactum* : 2 intermediate : 1 *vulgare* in the F_2. Other wheat characters in the F_2 gave the following ratios,—3 beardless : 1 bearded in beardless X bearded crosses; 3 velvet : 1 smooth in velvet X smooth chaffed crosses; 3 brown : 1 white in brown X white chaffed crosses. Professor Spillman observed that many plants occurred more or less intermediate between these types. Later (10) he mentioned winter wheat as showing dominance when crossed on spring wheat. Biffen (1) also found the beardless type dominant to the bearded type in six different crosses, two of which were grown in the F_3. The bearded types bred true to the beardedness, and one-third of the beardless type bred true, but the remainder produced beardless and bearded plants in the ratio 3 : 1. Velvet chaff also proved to be dominant to smooth chaff in eight of Biffen's crosses. When he analyzed the glume color of some of his wheat crosses he found both red and grey chaff dominant to white, but there occurred F_2 extremes both darker and lighter than the grey and white parents which bred true to type in subsequent generations. He also found red grain color to be a simple Mendelian dominant to white grain color in the following crosses. Rough Chaff X Gold Drop, Rivet X Polish, Manitoba X Rough Chaff. In two crosses keeled glumes were dominant to rounded glumes. Long heads are listed as dominant to club heads but in the descriptions irregularities, such as intermediates and greater head length than the long parent are mentioned. Hollow straw and rough leaves were dominant to solid straw and smooth leaves. When broad and narrow leaved varieties were crossed an F_2 ratio of 1 broad : 2

intermediate : 1 narrow, was obtained. An early ripening variety crossed on a late ripening variety likewise gave a 1 : 2 : 1 ratio. So, also for long and short glumes and long and short grain, but this correlation occurred: long glumes always bore long grain and short glumes always bore short grain. Susceptibility to yellow rust is shown to be dominant to immunity. In conclusion, Mr. Biffen says: "Mendel's laws of inheritnace apply to morphological, histological, and constitutional characters and one can probably recognize as many pairs of characters as there are minute differences between the varieties experimented with." In another article Biffen (2) showed that in barley the following characters segregated according to Mendelian expectation:

1. Sexless and staminate lateral florets.
2. Hermaphrodite and sexless lateral florets.
3. Staminate and hermaphrodite lateral florets.
4. Hooded and awned palea (floral glumes).
5. Black and white color in the palea.
6. Purple and white palea.
7. Narrow and broad (outer) glumes.
8. Lax and dense ears (long and club heads).
9. Adherent and non-adherent palea.
10. Brittle and tough rachis.

Wilson (12), working with oats, reports the dominance of black to white color of the floral glumes in three different crosses, altho the F_1 was lighter than the black parent. One cross, Waverly X Black Tartarian, did not conform to rule but gave only 1.5% of blacks in the F_2. In the same article Mr. Wilson describes a wheat cross of Red King X Rood Koren representing two pairs of characters, namely, beards and head length. Each pair is described as being a simple Mendelian pair of characters giving the ratio 3 short : 1 long and 3 beardless : 1 bearded. He also describes crosses of two and six row barleys as giving an F_2 ratio of 3 two-row : 1 six-row, but observed that in one cross intermediates, with only part of the lateral spikelets fertile, occurred.

Nilsson-Ehle (6) crossed black and white oats and obtained 3 black : 1 white in the F_2 with some of the crosses. In another cross the black parent carried a factor for grey which was hidden by the black color. The F_2 of this cross gave a modified di-hybrid ratio of 12 black: 3 gray: 1 white. In another cross the black color appeared to be the result of two

identical but independent factors, for the F_2 of this black crossed on white gave a ratio of 15 black: 1 white. He also found analogous results in certain wheat crosses. A wheat with brown chaff crossed on white chaff gave 15 brown: 1 white in the F_2. Experimenting with grain color in wheat he found one red variety that possessed three identical factors for red color each of which segregated independently of the other two. This interpretation was established by breeding a complete F_3 in which individuals with one, two, and three factors for redness were isolated. East and Emerson (3) have more recently shown similar duplication of factors in quantitative characters of maize, and East and Hayes (4) have further proved the cumulative somatic effects of multiple factors in a series of experiments with maize in which the maternal dominance of endosperm color was interpreted as being due to the fusion of the two female polar nuclei, each of which carried the color factor, with the opposing single male cell.

The evidence of these and other writers goes to show that a great number and variety of grain characters are Mendelian in inheritance. It also shows that occasional irregularities occur. Characters which are alike phenotypically may be unlike genotypically in different varieties. The glume color in oats and grain color in wheat noted above are illustrations of this. With the occurrence of duplicate factors and minor modifiers it is of interest and importance to know how constant these different characters are and how many of them will show irregularities and modifications when new varieties are used in the parentage and large numbers of offspring are analyzed.

INHERITANCE IN WHEAT

Description of the Characters Studied

Beards vs. No Beards. In some wheats the upper end of the floral glume terminates in a needle-like awn which varies in length from one to four inches. Such wheats are called *bearded* wheats. In others known as *beardless* the floral glume ends in a curved beak less than half an inch in length. In some beardless varieties the beaks may assume awn-like appearances on the floral glumes near the apex of the spike and may reach a length of an inch or more.

Long Head vs. Club Head. Under uniform conditions, the commercial wheats vary but little in the number of spikelets per head. The main difference between *long-headed* and *club* wheats is in the length of the rachis. The long-headed varieties vary in head-length from three to five inches. The club varieties vary from one to two inches.

FIG. 1.—PARENT TYPES OF WHEAT WITH F_1 BETWEEN
1. Turkey X Bluestem (Wash. No. 538).
3. Hybrid No. 143 (Wash. No. 590).
2. The resulting hybrid the first year after 1 and 3 were crossed. Note that it is somewhat intermediate in head length and has rudimentary beards.

White Grain vs. Red Grain. The Washington markets distinguish between *red* and *white* wheats. The difference seems to be in a brownish coloring matter laid down in the

remains of the nucellus just outside the aleurone layer of the so-called red wheats. This coloring matter is absent or nearly so in the white wheats. Some red wheats are redder than others. The clearness of the red is also affected by the character of the endosperm—whether horny or starchy.

Results After Hybridization

Beards vs. No Beards. Long Head vs. Club Head. Turkey X Bluestem (Wash. No. 538) is a winter variety of Turkey type with **bearded long head** and **red grain.** This wheat was originated at the Washington Experiment Station and has bred true to these factors for eight years.

Hybrid 143* (Wash. No. 590) is a wheat of Club type with **beardless club head** and **white grain.** It is usually grown as a winter variety but matures grain when planted in the spring. This wheat was originated at the Washington Experiment Station and has bred true to type for at least eleven years.

These two wheats were hybridized in 1911. Reciprocal crosses were made to check against a possibility of sex-linked characters. Thirty-three F_1 plants were obtained in 1912. It made no difference, either in the first or subsequent generations, which wheat was used as the staminate parent.

All the F_1 plants looked alike. They were slightly bearded, club-headed, but somewhat intermediate in length, and all had red grain. The seed of ten of these F_1 plants was planted each in a separate row. Each of the ten rows gave similar results. Since they did not show complete dominance in either case they produced nine different types according to beards and head length. (Color of grain is considered separately and will be discussed later). The following table gives the distribution of the nine types in the F_2 for each row. The numbers 12201, 12301, and 12401 represent the reciprocal cross of the other seven.

A study of Table I shows that full beards appeared on about one-fourth of the plants regardless of head-length. Also about one-fourth of the plants produced long heads regardless of whether beards appeared or not. That is, one-

*Hybrid 143 is a cross between White Track and Little Club, produced originally at Wash. Sta. in 1898 by Professor W. J. Spillman.

sixteenth of the total number of plants produced both long heads and full beards. By adding average percentages for the bearded vs. beardless characters, we get 26.7% BB, 49.2% Bb, and 24% bb—approximately the 1 : 2 : 1 ratio.

TABLE I.

F_2 Types Obtained by Crossing a Long-headed Bearded Wheat (Wash. 538) and a Club-headed Beardless Wheat (Wash. 590.)

Beards—BB
Slightly bearded—Bb
No beards—bb

Long head—LL
Almost club—Ll
Club head—ll

1913 Row No.	BB LL	BB Ll	BB ll	Bb LL	Bb Ll	Bb ll	bb LL	bb Ll	bb ll	Total No. Plants
11501	32	70	23	58	125	52	25	52	30	467
11601	24	46	17	35	72	33	15	30	17	289
11701	44	67	32	73	128	51	28	56	25	504
11801	11	46	13	43	77	19	14	31	11	265
11901	44	129	120	173	237	194	73	140	123	1233
12001	41	70	36	73	150	46	32	55	28	531
12101	54	116	52	100	146	85	52	67	59	731
12201	51	124	55	122	193	111	67	104	73	900
12301	65	130	47	126	215	147	45	85	77	937
12401	89	118	70	119	249	128	73	104	60	1010
Total	455	916	465	922	1592	866	424	724	503	6867
Av. % . . .	6.6	13.3	6.8	13.4	23.2	12.6	6.2	10.5	7.3	100.0

By adding the averages for the long vs. club characters we get 26.2% LL, 47% Ll, and 26.7% ll—not quite so close but still approximately the 1 : 2 : 1 ratio. A combination of both pairs of allelomorphs gives a close approximation to the ratio 4 : 2 : 2 : 2 : 2 : 1 : 1 : 1 : 1, which is the most probable

FIG. 2.—THE NINE TYPES RESULTING FROM A SINGLE F_1 PLANT (FIG. 1, NO. 2) IN THE F_2.
Nos. 1, 3, 7, and 9 breed true to head length and beard character—whether present or absent. 2 and 8 breed true to head length but produce 25% of bearded plants in the F_3. 4 and 6 breed true in respect to beards and no beards but produce 25% of long headed plants in the F_3. 5 is heterozygous for both factors and produces again in the F_3 these nine types in the same ratio. (F_2 ratio reading from left to right, 1 : 2 : 1 : 2 : 4 : 2 : 1: 2 : 1).

expectation for a di-hybrid if all of the heterozygous forms show phenotypic differences.

It should be noted, however, that the club headed plants, which were bearded, bore beards only about half as long as the beards on the long-headed plants which were bearded. Evidently the same factor that shortened the rachis could also shorten the beards, but had nothing to do with their appearance and non-appearance. The club headed plants also grew about eight inches shorter on the average than the long headed plants—another noteworthy case of dwarfing, but their straw length was more variable than either beards or head length—due in part to environmental conditions, but in part, no doubt, to heterozygosis of other hidden factors. In order to test the correctness of these assumptions, all the plants of row No. 11601 were planted the following year in 289 separate rows. One row did not germinate, the records of three others were lost in harvesting, but the 285 other rows produced 136,172 plants distributed according to the ratios in the following table. With the exceptions noted each row showed that its F_2 parent had been correctly classified.

TABLE II.

Accuracy of the F_2 Separation Tested by Seeding Each Plant in a Separate Row and Getting the F_3 Record.

Genotype.	F_2 Phenotypic Separation	Mistakes in Phenotypic Separation	F_2 Genotypic Segregation (As shown by F_3)	F_3 Phenotypic ratios
BB LL	22	None	24	100%
BB Ll	44	1 BBLL 5BBll	41	73.5 : 26.5
BB ll	18	3 BBLl	20	100%
Bb LL	35	1 BBLL	34	73.2 : 26.8
Bb Ll	71	8 Bbll, 9 bb-Ll, 1 bbll	60	52.8 : 19.7 : 19.6 : 7.8
Bb ll	35	4 BbLl, 3 bbll	40	70.6 : 29.4
bb LL	15	None	15	100%
bb Ll	28	3 BbLl, 5 bbll	29	71.9 : 28.1
bb ll	17	4 Bbll	22	100%
Total....	285	47	285	136,172 plants

It will be noted that the nine types assumed in the F_2 classification actually existed as shown by their breeding qualities in the F_3 phenotypic ratios. Except for the mis-

takes noted, the types classified as homozygous bred true. The types that were classified as being homozygous for one factor and heterozygous for the other, bred true for the homozygous factor and gave approximately the 3 : 1 ratio for the heterozygous factor. The type classified as doubly heterozygous gave approximately the 9 : 3 : 3 : 1 di-hybrid ratio. Owing to the large amount of material the types **Bb** and bb were put togeter and the types **Ll** and **ll** were put togther in the F_3 counts, for it takes considerable time and good judgment to distinguish between these types—but, time permitting, it could have been done.

The table shows the mistakes in the F_2 separation due to the close resemblance of the heterozygotes to the club and beardless homozygotes. In fact an average of one plant in six was placed in the wrong column. The 22 BBLL plants all bred true and one plant classified in the BBLl group produced only BBLL plants. Likewise one plant classified as a BbLL type gave a row with only BBLL plants. Five of the BBLl F_2 classifications produced only BBll plants. So, also for the other types, where the numbers in the column F_2 *Phenotypic Separation* do not tally with the column F_2 *Genotpyic Segregation* the excess number of plants in the F_2 column fell into the F_3 group which that type most closely resembled. This means an error in judgment of the type to which the F_2 plant belonged. It will be noticed that the largest error is shown in the plants that were supposed to be heterozygous in both respects. This is to be expected as there are three other groups which closely resemble this group—namely, the *heterozygous short* (Bbll), *beardless heterozygous* (bbLl), and *short beardless* (bbll) types. The striking thing is that there was not one of the 285 rows that would not readily classify in some **one** of the nine groups. The genotypes were represented distinctly by phenotypic differences. There was no complete dominance, and there was no evidence of linkage or cross-overs.

These same characters were also analyzed in the following spring varieties: (1) Brown's Glory, (2) Minnesota Bluestem, (3) Goldendale Bluestem, (4) Red Bluestem. Brown's Glory (Wash. No. 421) was obtained from Oregon in 1904. It breeds true to beards, club heards, and white grain Minnesota Bluestem 169 was obtained from the Minnesota station in 1903. It breeds true to beardless long heads and

red grain. Goldendale Bluestem was obtained in Goldendale, Washington, in 190 . It breeds true to beardless long heads and red grain. Red Bluestem has been grown at the Washington Station since 1905. It is constant for beardless long heads, but contrary to its name, produces white grain.

Three crosses of spring wheat containing the characters beards vs. no beards and long vs. club heads were made, to see whether these factors were allelomorphic in other varieties. The following results were obtained in 1912: 6 true F_1 plants from Brown's Glory X Goldendale Bluestem; 8 true F_1 plants from Goldendale Bluestem X Brown's Glory; 5 true F_1 plants from Red Bluestem X Brown's Glory; 26 true F_1 plants from Brown's Glory X Minnesota Bluestem 169.

The F_1 plants were all very much alike in respect to beards and head length. In these spring crosses, the Brown's Glory had the beards and the club head; all the others were beardless and long-headed. The F_1 plants were club-like but intermediate in length. They would be classed as beardless even tho the upper floral glumes bore distinct beards averaging about three-fourths of an inch in length. Ten of these F_1 plants were seeded by hand the following spring in separate rows. No. 15001 was a Brown's Glory and Goldendale Bluestem cross. No. 15101 represented the reciprocal cross—Goldendale Bluestem X Brown's Glory. No. 15201 was a cross of Red Bluestem and Brown's Glory. All of the others were crosses of Brown's Glory and Minnesota Bluestem.

The following table gives the F_2 distribution:

TABLE III.

F_2 Types Obtained by Crossing a Club-headed, Bearded Wheat and a Long-headed Beardless Wheat.

Beards—BB
Slightly bearded—Bb
No beards—bb

Long head—LL
Almost club—Ll
Club head—ll

1913 Row. No.	BB LL	BB Ll	BB ll	Bb LL	Bb Ll	Bb ll	bb LL	bb Ll	bb ll	Total No plants
15001	89	187	107	181	417	168	109	172	137	1567
15101	99	182	101	206	347	152	108	189	144	1528
15201	64	111	31	114	246	116	58	93	59	892
15301	54	81	34	101	196	68	56	64	55	709
15401	59	128	61	137	280	82	41	119	75	982
15501	63	95	32	82	209	56	57	108	39	741
15601	58	116	63	119	256	76	60	134	54	936
15701	22	42	20	44	103	40	22	60	26	379
15801	32	65	46	75	157	77	56	90	51	649
15901	60	93	58	102	229	98	65	90	63	858
Total...	600	1100	553	1161	2440	933	632	1119	703	9241
Av. %..	6.5	11.9	6.0	12.6	26.4	10.1	6.8	12.1	7.6	100

Table III shows the expected 4 : 2 : 2 : 2 : 2 : 1 : 1 : 1 : 1 segregation for the spring wheats and looks almost like the winter wheat segregation shown in Table I.

The different crosses all produced similar types in the F_2 with regard to beards and head length. Table IV is a summary of Tables I and III.

TABLE IV.

Percentages of Types Found Compared with Dihybrid Ratio. Summary of Tables I and III.

Genotypes	Distribution of Types		Theoretical Per cent Distribution	Difference of Theoretical and Actual
	No. Plants	Per cent		
BBLL.....	1055	6.55	6.25	.30
BBLl......	2016	12.52	12.50	.02
BBll.......	1018	6.32	6.25	.07
BbLL......	2083	12.93	12.50	.43
BbLl......	4032	25.03	25.00	.03
Bbll.......	1799	11.17	12.50	1.33
bbLL......	1056	6.56	6.25	.31
bbLl......	1843	11.44	12.50	1.06
bbll.......	1206	7.49	6.25	1.14
Total......	16108	100.01	100.00	Avg. .52

Table IV shows that for the varieties of wheat studied beards and head length are undoubtedly two independent simple allelomorphs. It also shows the accuracy of Mendelian segregation when large numbers are used. We have here an average deviation of only .52 of one per cent from the most probable mathematical expectation. Table II shows that there is a real phenotypic difference between the homozygous and heterozygous forms, and that either long or short or beardless or bearded plants may be selected in the second generation that will breed true to these factors. It is noteworthy that no distinct homozygous intermediates were found in the F_3 for either head-length or beardedness.

White Grain vs. Red Grain. Red wheat has a brownish coloring matter deposited in the remains of the nucellus—just outside of the aleurone layer. This coloring matter is absent, or nearly so, in white grain. The redness of a wheat depends upon the amount of this brownish pigment present. It may vary from an almost unbroken layer to a few scattered granules. It is easily affected by moisture, as may be seen in wheats bleached by rain.

Each of the crosses just discussed, with the exception of Brown's Glory X Red Bluestem, represented the characters *red* vs. *white* grain. In every case the club-headed parents had white grain and the long-headed parents bore red grain.

All of the F_1 plants bore *red* grain, which to all appearances, was just as red as the red parent. The seeds were in-

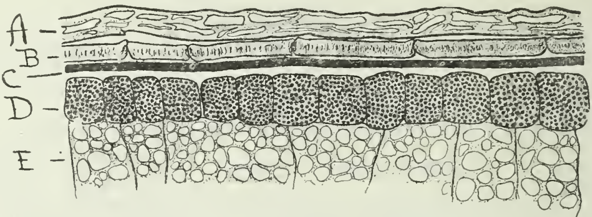

FIG. 3.—SECTION OF A SEED OF RED WHEAT.

The color is located in the remains of the Nucellus.

A. Pericarp.

B. Outer Integument.

C Remains of the Nucellus. Contains the brownish pigment that distinguishes red and white wheats.

D. Aleurone cells.

E. Starch cells. (Magnified X 429. Drawing by Karl Sax).

termediate between the two parents in size and shape, and variable as to texture, varying from horny to starchy.

When the F_2 appeared only an occasional plant could be found which bore white grain. Rows 11601 and 11801 of Table I were saved, each plant threshed by itself, and the color of the grain compared. It was found that some of the plants had *dark red* some had *medium red,* some had *light red,* and a few had *white* grain.

No. 11601 had an F_2 grain color distribution as follows: 106 plants were *dark red,* 112 plants were *medium red,* 56 plants were *light red,* and 6 plants were *white.*

The plants of row No. 11801 were separated as follows: 123 plants produced *dark red,* 119 *medium red,* 10 *light red,* tnd 7 *white* grain. The separation of the different shades of red was complicated by the presence of horny and starchy kernels in varying quantities in the different plants. (Horny kernels appear to be a deeper red than they really are). The classes, dark, medium, and light red were purely arbitrary standards. The reds might have been divided into four or

five classes. The red grandparent was used as the standard of comparison for the dark red class, an F_2 intermediate between dark and light red was used as the standard for the medium red class and a light red F_2 was picked out as a standard for the light red class. The white grandparent was used as the standard of comparison for the white class. The following table shows the distribution of these four classes in the two F_2 families studied.

TABLE V.

Distribution of Color in F_2 of Hybrid 143 (White) and Turkey X Bluestem (Red). (The F_1 was Dark Red).

1913 Row Number	No. plants Dark Red	No. Plants Medium Red	No. Plants Light Red	No. Plants White	Total Plants
11601	106 (37.9%)	112 (40%)	56 (20%)	6 (2.1%)	280
11801	123 (47.5%)	119 (46%)	10 (3.9%)	7 (2.7%)	259
Total......	229 (42.5%)	231 (42.9%)	66 (12.2%)	13 (2.4%)	539
Theoretical	(42.2%)	(42.2%)	(14.1%)	(1.6%)	
Difference.	(.3%)	(.7%)	(1.9%)	(.8%)	

TABLE VI.

Percentage Distribution of White Grain Produced from F_2 Parents Carrying 3 Independent Heterozygous Factors for Redness (Rr, R′r′ and R″r″).

1914 Row Number	Per cent of White	1914 Row Number	Per cent of White	1914 Row Number	Per cent of White
13401	1.2	22501	2.2	29201	1.7
14401	3.3	22601	2.1	29301	2.8
14701	3.2	24101	0.5	29701	3.3
15601	1.4	24901	3.7	30101	3.3
16301	3.7	25201	1.5	35201	1.7
16701	2.9	25401	3.2	36001	3.3
17801	0.3	25701	1.5	36301	3.5
19401	0.3	26001	1.5	36601	1.7
20701	3.3	27801	0.5	37001	2.4
22401	2.9	28001	0.6	38401	0.5

Total number of rows 30
Average per cent white, 2.1.

A study of Table V suggests the probability that there were *three completely dominant factors* each of which contributed redness to the grain independently of the other two and had a cumulative effect in this particular cross.

A single factor difference between red and white would have given a 3 : 1 ratio in which (assuming complete dominance) the reds would show the same intensity of redness.

The results show an entirely different ratio, and reds varying greatly in intensity. If a *two-factor* difference, in which each factor is the exact duplicate of the other, be assumed, the di-hybrid ratio 9 : 3 : 3 : 1 would be modified to a ratio of 9 : 6 : 1 in which 9 represents all the possible combinations in 16 where both factors would be present in the same individual. The two 3 : 3 types of the regular di-hybrid ratio could be added together, for in the premises it is assumed that the two factors are identical in somatic effect. In the absence of both factors 1 in 16 would be white. In this case there would be two intensities of red: 9 dark red : 6 intermediate : 1 white. The results do not fit this assumption for there were not enough whites found, and the reds showed too much variation. The *three identical factor* hypothesis seems the most tenable, for in it there would be but one white in 64. There would be three shades of red, depending upon the number of factors present. The tri-hybrid ratio 27 : 9 : 9 : 9 : 3 : 3 : 3 : 1 would be modified to 27 : 27 : 9 : 1. This modified ratio reduced to a percentage basis would be 42.2% : 42.2% : 14.1% : 1.6% which, as Table V shows, very nearly fits the results as found. A somewhat superficial examination in the field of the F_2 spring wheats of Table III indicated that less than 2% of the plants produced white grain, and that there were different intensities of red among the plants classified as *red*. Four selected red F_2 spring plants gave in the F_3 the following results: one bred true to redness, one produced several white plants (exact counts were not taken) the other two were threshed in bulk. One had 16 white kernels in a thousand, the other had only three. Four F_2 spring plants bearing white grain were also planted. They bred true to white color in the F_3. It seems not too much to suppose that the same type of color inheritance occurred in both winter and spring wheat.

Row 11601 of Table I was carried complete thru the F_3. In 1911 a flower of Hybrid 143 (Wash. No. 590)—a beardless club *white* wheat—was emasculated and the next day pollinated with pollen from a head of Turkey X Bluestem (Wash. 538)—a long-headed bearded *red* wheat. This flower produced a little shriveled red kernel which in 1912 produced a red seeded plant (F_1), the seeds of which in 1913 produced 280 plants (F_2). Of these, 106 had dark red seeds, 112 had medium red seeds, 56 had light red seeds, and 6 had white

seeds. These 280 F_2 plants produced 280 rows of F_3 grain in 1914 colored as follows: 162 rows produced red grain only, but these were different intensities of red; 30 rows produced red and white grain in the ratio of 63 : 1; 48 rows produced red and white grain in the ratio of 15 : 1; 28 rows produced red and white grain in the ratio of 3 : 1; 6 rows produced only white grain.

A study of Tables VI to IX will show the percentage distribution of white grain in the F_3 by families (offspring of F_2 plants).

In order to simplify the tabular descriptions it will be assumed that one factor RR when present alone produces a light red color in the grain—which color, however, is not any lighter in the heterozygous condition, Rr. In the absence of RR or Rr, no red color would develop and the grain would be white, rr. The second factor R′R′ segregates independently of RR and acting alone it would produce identical results. So,

TABLE VII.

Percentage Distribution of White Grain Produced from F_2 Parents Carrying 2 Independent Heterozygous Factors for Redness (Rr R′r′ or Rr R″r″ or R′r′ R″r″).

1914 Row Number	Per cent of White	1914 Row Number	Per cent of White	1914 Row Number	Per cent of White
12501	5.4	22001	7.8	32901	5.8
12601	4.7	23401	15.3	33201	6.9
13701	8.8	23501	6.9	34001	7.3
14101	4.6	25901	6.2	34801	7.2
16101	7.3	26501	11.2	35001	10.9
17001	7.0	26801	9.0	35301	11.9
17101	8.5	27201	7.2	35901	8.7
18101	5.9	27601	5.8	37501	6.5
18201	6.3	29801	4.4	38101	4.2
18301	7.3	30201	5.4	38501	5.6
18901	5.6	31401	6.2	38601	5.0
20401	15.2	31501	5.8	38701	9.8
20601	7.4	31701	8.4	39501	6.0
21001	13.5	32201	6.2	39801	5.4
21501	11.8	32301	6.1	39901	8.8
21801	4.5	32501	6.4	40101	15.4

Total number of rows, 48.
Average per cent white, 7.6.

also for the third factor R″R″. Any two acting together are the equivalent of any other two, and are cumulative in effect,—that is, they are intermediate between light red (one factor) and dark red (three factors).

Table VI gives the results of 30 of the 280 F_3 rows harvested in 1914. These rows appear to have originated from F_2 plants which were heterozygous for three factors for red color. The average gives about one white seeded plant in 50. The theoretical ratio is 1 in 64.

Table VII gives the results of 48 of the 280 F_3 rows harvested in 1914. These rows had so many white seeded plants that it seemed probable that one factor for redness had been eliminated and that only two remained. There was an average of about one white plant in 14 in this group. The theoretical ratio is 1 : 15.

TABLE VIII.

Percentage Distribution of White Grain Produced from F_2 Plants Carrying a Single Heterozygous Factor for Redness (Rr or R′r′ or R″r″).

1914 Row Number	Per cent of White	1914 Row Number	Per cent of White	1914 Row Number	Per cent of White
15201	25.2	21101	19.4	32801	18.3
16401	29.0	23001	28.5	35701	25.4
17201	22.4	24301	20.2	36101	23.7
17601	23.2	24501	24.8	37301	23.2
18001	22.5	24801	22.9	37701	25.3
18801	17.4	25001	20.1	37801	19.9
19301	38.0	29401	28.5	37901	36.1
19901	17.7	29601	22.0	39601	16.4
20001	24.7	30301	19.2	40001	22.6
				40401	23.3

Total number of rows, 28.
Average per cent white, 23.5.

Table VIII gives the results of 28 of the 280 F_3 rows harvested in 1914 . The percentage of white grain runs so high in these rows that the simple Mendelian ratio 1 : 3 very nearly fits the average obtained. Evidently two of the three factors for redness had been eliminated in the F_2.

TABLE IX.

Summary of Color Study in Wheat—Segregation of F_3 by Families Compared with Tri-hybrid Hypothesis.

No. in Each Class	F_2 Genotypic Construction	F_3 Color Types	No. families Found	Actual Per cent	Theoretical Per Cent
1	RR R'R' R''R''[1]	Dark red	48	17.2	1.6
1	RR R'R' r''r''[2]				
1	RR r'r' R''R''[2]	Medium red	27	9.6	4.7
1	rr R'R' R''R''[2]				
1	RR r'r' r''r''[3]				
1	rr R'R' r''r''[3]	Light red	28	10.0	4.7
1	rr r'r' R''R''[3]				
2	RR R'R' R''r''[1]				
2	RR R'r' R''R''[1]				
2	Rr R'R' R''R''[1]				
4	RR R'r' R''r''[1]				
4	Rr R'R' R''r''[1]				
4	Rr R'r' R''R''[1]	Mixed red	65	23.2	46.9
2	RR R'r' r''r''[2]				
2	RR r'r' R''r''[2]				
2	Rr r'r' R''R''[2]				
2	Rr R'R' r''r''[2]				
2	rr R'R' R''r''[2]				
2	rr R'r' R''R''[2]				
8	Rr R'r' R''r''[1]	63 red : 1 white	30	10.7	12.5
4	Rr R'r' r''r''[2]				
4	Rr r'r' R''r''[2]	15 red : 1 white	48	17.2	18.7
4	rr R'r' R''r''[2]				
2	Rr r'r' r''r''[3]				
2	rr R'r' r''r''[3]	3 red : 1 white	28	10.0	9.4
2	rr r'r' R''r''[3]				
1	rr r'r' r''r''[4]	Pure white	6	2.1	1.6
			280	100%	100%

[1]Dark Red Phenotypes in F_2
[2]Medium Red Phenotypes in F_2
[3]Light Red Phenotypes in F_2.
[4]White Phenotypes in F_2.

Table IX summarizes the investigation of the color of wheat. The genotypic construction of the F_2 is computed as if color represented a tri-hybrid. The results nearly fit the case. It was difficult to distinguish between the types *fixed* red and *mixed red* because the horniness and starchiness of the different seeds changed the appearance of the color. Evidently many that were classified as *dark*, *medium*, and *light*

red woul prove by subsequent breeding to be *mixed* red. The total of the dark, medium, light, and mixed reds very nearly equals the theoretical expectation. (Theoretical, 57.9%; found, 60%). The number of families producing the different ratios of white grain are within less than 2% of the expectation.

While the assumption of three independent factors working together seems to best explain the color phenomena of these particular wheat crosses, there is some evidence that red color is brought about in a different manner in other crosses. We have two cases in which a red wheat was produced by crossing two white wheats but the counts were not taken of the percentage distribution of these types. This would indicate another series of factors and inhibitors entirely different from those in the investigation just described, but which to all appearances could produce the same somatic effect.

Still another case arose in 1915 in which the pollen from a red seeded wheat fertilizing the ovaries of a white seeded variety produced *red* seeds. This is not analogous to xenia in the endosperm of other angiosperms, as the color is located in the seed coat.

INHERITANCE IN BARLEY

Description of Characters Studied

Beards vs. Hoods. The floral glumes of bearded barleys bear needle-like prolongations at the apex, two to five inches in length which are called *beards.* The *hood* of the hooded barleys is a small, three angled, hood-like swelling borne at the apex of the floral glume or upon a short beard. The hood is really a small, secondary, aborted floret which in rare instances may set grain. These varieties are often called *beardless* barleys.

Bald vs. Covered Grain. In threshing, the *bald* barleys shed their floral glumes and paleae as chaff, leaving the grain free of hulls as in wheat. The *covered* varieties when threshed retain the floral glumes and paleae which parts adhere to the caryopsis.

Six-Row vs. Two-Row Heads. All barleys produce three single-flowered spikelets at each joint of the rachis. Since the joints of the rachis alternate first on one side then on the other, it gives the head the appearance of having *six rows* of seeds provided all the spikelets are fertile. In *two-rowed*

barleys only the *median* spikelets produce seeds. The two lateral spikelets are sterile. Usually they develop anthers without the female elements. Sometimes both organs are present but abortive. In *Hordeum dicipiens* the four lateral rows are rudimentary and without floral organs.

Winter vs. Spring Type. Under the climatic conditions which obtain at Pullman, Wash., the true *winter* barleys require the rest period of winter after germination before they mature. If planted in the spring they tiller profusely, but will not head out. While some of the *spring* barleys live thru the winter fairly well, most of them reach their best development when planted in the spring and complete the life cycle without the winter rest in the vegetative state.

FIG. 4.—PARENT BARLEYS WITH F_1 BETWEEN

1. Excelsior, a six-row bald barley. 3. Rice, a two-row hulled variety. 2. An F_1 hybrid of Excelsior X Rice. The hulled character is 25 completely dominate. Part of the lateral spikelets are fertile, but are only slightly bearded in the F_1.

Results After Hybridization

Beards vs. Hoods. Bald vs. Covered Grain. A cross was made in 1910 which made possible the working out of these two allelomorphic pairs together. The male parent (Wash. No. 874) was **bearded** and **bald**. The female parent (Wash. No. 873) was **hooded** and **covered**. The 84 F_1 plants produced in 1911 were all **hooded** and **covered**. The offspring of these in 1912 gave approximately the 9 : 3 : 3 : 1 ratio. It was impossible to separate the heterozygotes from the dominate homozygotes. The following table shows the varying percentage of 13 such F_2 families.

TABLE X.

Distribution of Barley Types in the F_2 of No. 874 X No. 873. The Offspring of 13 F_1 Plants that were Hooded and Covered but which Carried the Bearded and Bald Factors as Recessives.

1912 Row	Bearded & Bald		Bearded and Covered		Hooded and Bald		Hooded and Covered		Total No Plants
	No. Plants	Per cent	No. Plants	Per cent	No. Plants	Per cent	No. Plants	Per cent	
16401	33	8	61	15	79	20	241	58	414
16501	33	8	73	17	72	17	243	58	421
16601	35	7	95	20	78	16	266	56	474
16701	29	6	95	18	95	18	300	58	519
16801	19	10	31	16	53	27	93	47	196
16901	19	5	76	20	76	20	206	55	377
17001	19	7	63	20	61	19	166	54	309
17101	40	6	115	18	119	19	360	57	634
17201	25	7	69	17	85	20	230	56	409
17301	34	7	92	18	98	20	276	55	500
17401	9	5	29	17	34	20	100	58	172
17501	29	6	89	19	74	16	278	59	470
17801	5	19	6	22	3	11	13	48	27
Total...	329		894		927		2772		4922
Average	6.7%		18.2%		18.8%		56.3%		
Theoret.	6.25%		18.75%		18.75%		56.25%		

By adding the columns of bearded in Table X we get 24.9%. The sum of the hooded types gives 75.1%. This is within .1% of the exact 1 : 3 ratio. Likewise adding the bald types and comparing the result with the sum of the covered types we get the ratio 25.5% : 74.5%. This is within .5% of the expected 1 : 3 ratio. These characters are therefore strictly allelomorhpic in the F_2 and confirm the work of other investigators on these same characters.

To determine the germinal constitution of these four types, the 172 plants of Row No. 17401 of Table X. were planted each in a separate row and when mature the different

types were separated. The 9 bearded bald plants all bred true. Eight of the 29 bearded covered plants bred true. The other 21 all bred true to beards, but not to the covered character. Table XI gives the segregation of the progeny of these heterozygotes. Ten of the 34 hooded bald plants bred true to both hoods and baldness. The other 24 produced only bald plants, but some were bearded and some were hooded. Table XII gives the distribution of plants that were heterozgous for the hooded factor. Only 10 of the 100 hooded covered plants bred true. Thirty-one bred true to the hooded character, but gave both bald and covered plants. Table XIII gives the distribution of these bald and covered plants. Eighteen of the 100 hooded covered plants bred true to the covered character, but produced both bearded and hooded plants. Table XIV gives the distribution of these two types. The other 41 plants produced all four types. They did not breed true to either character. Table XV gives the distribution of these four types.

TABLE XI.

F_3 Barley Types Springing from 21 F_2 Bearded Covered Plants that did not Breed True to the Covered Factor.

Row No.	Bearded bald		Bearded Covered		Total Plants
	No. Plants	Per cent.	No. Plants	Per cent.	
5201	78	26.9	212	73.1	290
5401	44	24.0	139	76.0	183
5501	56	30.3	129	69.7	185
5701	56	23.1	182	76.9	238
5801	57	26.4	159	73.6	216
6001	34	26.2	96	73.8	130
6101	29	21.8	104	78.2	133
6201	46	23.1	153	76.9	199
6301	27	32.5	56	67.5	83
6501	10	23.3	33	76.7	43
6601	8	44.4	10	53.6	18
6701	41	24.7	125	75.3	166
6801	20	32.8	41	67.2	61
7001	47	29.5	112	70.5	159
7101	145	31.5	315	68.5	460
7201	40	25.6	116	74.4	156
7301	13	30.2	30	69.8	43
7401	143	30.2	330	69.8	473
7501	35	28.2	89	71.8	124
7601	5	25.0	15	75.0	20
7701	55	29.1	134	70.9	189
Total....	989		2580	72.3	3569
Average..	47.1	27.7	122.9		170

FIG. 5.—F_2 TYPES RESULTING WHEN BARLEYS (EXCELSIOR AND RICE) SHOWN IN FIG. 4 ARE CROSSED.

TABLE XII.

F_3 Barley Types Springing from 24 F_2 Hooded Bald Plants that did not Breed True to the Hooded Factor.

Row No.	Bearded Bald		Hooded Bald		Total No Plants
	No. Plants	Per cent.	No. Plants	Per cent.	
4601	21	25.6	61	74.4	82
4801	59	25.6	171	74.3	230
4901	30	25.0	90	75.0	120
5101	9	26.5	25	73.5	34
5201	39	26.5	108	73.5	147
5301	25	24.8	76	75.2	101
5401	33	25.4	97	74.6	130
5601	17	25.4	50	74.6	67
5901	45	27.8	117	72.2	162
6101	26	22.3	105	77.7	131
6201	15	26.6	42	73.4	57
6401	26	23.8	83	76.2	109
6501	82	26.9	222	73.1	304
6701	68	24.6	208	75.4	276
6801	2	14.3	12	85.7	14
7001	35	21.3	129	78.7	164
7101	21	27.2	56	72.8	77
7201	31	20.9	117	79.1	148
7301	97	25.7	280	74.3	377
7401	21	23.9	67	76.1	88
7501	26	21.7	57	78.3	83
7601	19	26.0	54	74.0	73
7701	80	22.5	279	77.5	359
7801	34	20.7	130	79.3	164
Total.......	861		2636		3497
Average....	35.9	24.6	109.9	75.4	145.7

TABLE XIII.

F_3 Barley Types Springing from 31 F_2 Hooded Covered Plants that did not Breed True to the Covered Factor.

Row. No.	Hooded Bald		Hooded Covered		Total
	No. Plants	Per cent	No. Plants	Per cent.	No. Plants
9101	4	11.7	30	88.3	34
10701	117	27.5	308	72.5	425
10801	41	20.8	156	79.2	197
11101	20	24.4	62	75.6	82
11401	45	27.9	116	72.1	161
12201	43	28.4	108	71.6	151
12501	60	27.9	155	72.1	215
13201	45	21.5	164	78.5	209
13401	46	24.3	143	75.7	189
13501	82	30.5	187	69.5	269
13901	18	35.3	33	64.7	51
14201	22	36.1	39	63.9	61
14301	71	26.6	196	73.1	267
14601	39	33.3	78	66.7	117
14801	49	26.5	135	73.5	184
16201	66	25.4	194	74.6	260
16301	71	27.0	192	73.0	263
16401	53	25.8	152	74.2	205
16501	103	24.4	319	75.6	422
16701	34	29.6	81	70.4	115
16801	4	23.5	13	76.5	17
16901	56	24.6	171	75.4	227
17101	86	27.1	227	72.9	313
17901	33	20.2	130	79.8	163
18001	31	22.8	99	76.2	130
18101	54	26.7	148	73.3	202
18301	50	21.7	180	78.3	230
18501	77	27.9	199	72.1	276
18601	44	23.4	144	76.6	188
18701	69	31.7	151	68.3	220
18801	23	19.2	97	80.8	120
Total.......	1556		4407		5963
Average	50.2	26.1	142.2	73.9%	192.4

TABLE XIV.

F_3 Barley Types Springing from 18 F_2 Hooded Covered Plants that did not Breed True to the Hooded Factor.

Row. No.	Beard Covered		Hooded Covered		Total No. Plants
	No. Plants	Per cent.	No. Plants	Per cent	
8501	17	23.0	57	77.0	74
9901	13	24.1	41	75.9	54
10401	69	26.8	188	73.2	257
11701	43	27.0	116	73.0	159
12401	20	21.7	72	78.3	92
13101	30	25.6	87	74.4	117
13301	4	25.0	12	75.0	16
14401	54	22.6	185	77.4	239
14501	36	24.0	124	76.0	160
15201	56	25.1	167	74.9	223
15301	17	17.6	79	82.4	96
15701	17	19.1	72	80.9	89
16001	57	17.4	270	82.6	327
16101	6	18.2	27	81.8	33
16601	30	27.3	80	72.7	110
17501	23	25.2	68	74.8	91
17701	47	26.1	133	73.9	180
18901	66	22.6	226	77.4	292
Total	605		2004		2609
Average	33.6	23.2%	111.3	76.8	144.9

TABLE XV.

F_3 Barley Types Springing from 41 F_2 **Hooded** Covered Plants that Breed True to **Neither the** Hooded nor the Covered Factors.

Row No.	Bearded Bald		Bearded Covered		Hooded Bald		Hooded Covered		Total No.
	No. plants	Per cent	No. plants	Per cent	No. Plants	Per cent	No. plants	Per cent	Plants
8001	3	5.5	15	27.7	15	27.7	21	38.9	54
8401	8	9.3	14	16.3	20	23.2	44	51.1	86
8601	0	0.0	4	17.4	3	13.0	16	69.6	23
8801	24	6.2	61	15.8	73	18.9	227	58.9	385
9001	13	10.0	38	29.2	18	13.8	61	46.9	130
9301	7	5.6	21	16.8	25	20.0	72	57.6	125
10101	15	5.5	54	19.7	50	18.3	154	56.4	273
10201	4	6.6	12	20.0	13	21.6	31	51.6	60
10301	18	9.1	33	16.7	44	22.3	102	51.7	197
10501	13	9.2	40	28.6	21	15.0	66	47.1	140
10901	10	9.0	16	14.4	20	18.0	65	58.6	111
11001	15	5.1	70	24.0	34	11.6	172	59.1	291
11201	7	4.4	31	19.4	22	13.7	100	62.5	160
11501	9	18.0	00	00.0	6	12.0	35	70.0	50
11601	10	8.1	29	23.5	29	23.5	55	44.7	123
11901	17	5.6	53	17.5	67	22.1	166	54.8	303
12001	6	6.5	17	18.5	27	29.4	42	45.6	92
12101	11	11.4	22	22.9	19	19.8	44	45.8	96
12601	3	4.8	15	24.2	15	24.2	29	46.8	62
12701	28	7.0	87	21.7	79	19.7	206	52.5	400
12801	3	8.8	2	5.9	6	17.6	23	67.6	34
12901	6	6.1	21	21.4	19	19.4	52	53.1	98
13001	27	7.3	69	19.3	68	19.0	193	54.1	357

TABLE XV—(Continued).

Row No.	Bearded Bald		Bearded Covered		Hoodod Bald		Hoodod Covered		Total No. Plants
	No. Plants	Per cent	No. Plants	Per cent	No. Plants	Per cent	No. Plants	Per cent	
13601	13	6.7	33	17.1	48	24.8	99	51.3	193
13701	13	6.6	41	20.9	35	17.8	107	54.6	196
13801	4	4.8	13	15.6	16	19.1	50	60.2	83
14001	3	3.0	14	14.1	23	23.2	59	59.6	99
14101	9	4.9	37	20.2	25	13.6	112	61.2	183
14901	4	7.0	10	17.5	10	17.5	33	57.9	57
15001	9	8.1	20	18.0	20	18.0	62	55.8	111
15101	21	8.2	45	17.2	43	16.4	152	58.2	261
15501	14	3.6	73	19.1	64	16.7	232	60.6	383
15601	7	11.6	14	23.3	13	21.7	26	43.3	60
15801	16	4.9	48	14.6	94	28.6	170	51.8	328
15901	48	10.9	74	16.8	81	18.4	237	53.8	440
17001	12	5.5	38	17.5	47	21.7	123	55.9	220
17301	31	8.4	73	19.8	69	18.7	195	53.0	368
17601	40	11.1	62	17.2	83	23.0	176	48.7	361
17801	7	6.7	23	21.9	21	20.0	54	51.4	105
18201	12	5.1	47	20.1	41	17.5	134	57.2	234
18401	19	5.3	76	21.0	80	22.1	186	51.5	361
Total...	539		1465		1506		4383		7893
Average.	13.1	6.8%	35.7	18.6%	36.7	19.1%	106.9	55.5%	192.5

It will be seen from Tables XI to XV that there were five different kinds of heterozygous F_2 barley plants in row No. 17401 of Table X. Four of these types were heterozygous for but one factor and gave approximately a 1 : 3 ratio in the F_3. One type was heterozygous for both factors and gave a ratio of 1 : 3 : 3 : 9. But each of the four F_2 types observed and tabulated in Table X, namely, Bearded Bald, Bearded Covered, Hooded Bald, and Hooded Covered, had a few plants that bred true to those characters. They were homozygous for *both* factors. Adding the homozygous and the heterozygous types we see that from a hereditary standpoint there were *nine* types in the F_2 instead of four.

A summary of the hereditary performance of the 172 plants is given in Table XVI.

TABLE XVI.

Performance of F_3 Barley from F_2 Row No. 17401 of Table X Summarized.

Types Found In F_2	Germinal Constitution	No. of F_2 Plants Found	Rows resulting in F_3	Ratio of Plants in F_3 Rows
Bearded Bald	BB AA	9	9	100% pure bearded bald
Beaded Covered	BB Aa	29	21	1 bald : 3 covered (all bearded)
Beaded Covered	BB aa		8	100% pure bearded covered
Hooded Bald	Bb AA	34	24	1 bearded : 3 hooded (All bald)
Hooded Bald	bb AA		10	100% pure hooded bald
Hooded Covered	Bb Aa	100	41	1 : 3 : 3 : 9 all types
Hooded Covered	Bb aa		18	1 bearded : 3 hooded (all covered)
Hooded Covered	bb Aa		31	1 bald : 3 covered (all hooded)
Hooded Covered	bb aa		10	100% pure hooded covered.

Reducing the four F_2 phenotypes 9 : 29 : 34 : 100 to a percentage ratio and comparing it with the theroetical we get the following:

Found—Bearded Bald 5.2%: Bearded Covered 16.9%: Hooded Bald 19.8%: Hooded Covered 58.1%.

Theroetical—Bearded Bald 6.25%: Bearded Covered 18.75%: Hooded Bald 18.75%: Hooded Covered 56.25%.

The difference between the actual and theoretical is less than 2%. Reducing the genotypes, as found by the performance of the rows in the F_3, to a percentage ratio we get the following:

Found—BBAA 5.2% : BBAa 12.2% : BBaa 4.6% : BbAA 14% : bbAA 5.8% : BbAa 23.8% : Bbaa 10.5% : bbAa 18.5% : bbaa 5.8%.

Thereotical—BBAA 6.25% : BBAa 12.5% : BBaa 6.25% : BbAA 12.5% : bbAA 6.25% : BbAa 25% : Bbaa 12.5%: bbAa 12.5% : bbaa 6.25%.

With the exception of the bbAa type the F_3 segregation shows a close approximation to the expected number of plants.

Another cross was made between two barleys illustrating the genetic segregation of the bald vs. covered factors. The parent barleys were both hooded and all the offspring were hooded. One parent, Wash. 875, produced *bald* grain, the other, Wash. 873, *covered* grain. Twenty-three F_1 plants each produced covered grain. Ten of these F_1 plants produced an average the following year of 25.6% of *bald* plants and 74.4% of *covered* plants. Selections of the covered plants seeded the next year showed that there were Aa plants and aa plants, for part of the selections produced 25% of bald plants and the others produced all covered plants in the F_3.

Another cross was made in which the bald and covered allelomorphs gave the 1 : 3 ratio in the F_2. In this cross one parent, Wash. 871, was two-rowed and bearded. The other, Wash. 873, was six-rowed and hooded, but that did not affect the segregation of the bald and covered plants. In this cross the F_2 bearded and hooded plants also segregated in the 1 : 3 ratio. The average of families, containing 6693 plants was 26.9% bearded, 73.1% hooded.

Six-row vs. Two-row Heads The two-row barleys have *sterile lateral* spiklets; these sterile spikelets have neither

beards nor hoods at the apex. The *median* spikelets which are fertile may bear either beards or hoods.

Two barleys, Rice and Beardless, were crossed in 1910. The *Rice barley, which was used as the staminate parent, was two-rowed and bearded. The pistillate parent, Beardless, was six-rowed and hooded. The F_1 bore fertile lateral spikelets which were smaller than in most six-row varieties and which were without floral appendages. The median spikelets bore hoods, showing the dominance of that character.

The F_2 generation produced six types as follows:

1. Two-rowed bearded.
2. Two-rowed hooded.
3. Six-rowed with beards on median spikelets only.
4. Six-rowed with hoods on median spikelets only.
5. Six-rowed with all the spikelets bearded.
6. Six-rowed with all the spikelets hooded.

Leaving out the bearded vs. hooded factors (which segregated independently into 26.7% bearded and 73.3% hooded) there were three types with reference to the number of rows: (a) two-rowed in which the lateral spikelets were all sterile, (b) six-rowed in which the lateral spikelets bore neither beards nor hoods—and usually part of them were sterile, especially on the later maturing spikes, (c) six-rowed in which all or nearly all of the lateral spikelets bore grain and grew the same kind of an appendage (either beard or hood) that the median spikelets possessed. The distribution of F_2 plants in 13 families is given in the following table:

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*Mr. H. V. Harlan, Agronomist in charge of Barley Investigation for the U. S. D. A., writes concerning Rice barley: "We received the seed of this variety from Hagge & Schmidt, Erfurt, Germany. Apparently it was quite widely cultivated in England during the 17th century, but since it has gradually disappeared......It is a spring variety that is typically 2-rowed."

TABLE XVII.

F_2 Barley Types from 13 F_1 Plants.

The male grandparent was two-rowed, the female grandparent was six-rowed. The F_1 classified as six-rowed but the lateral spikelets were beardless and and part of them were sterile.

Row No.	Year Tested	Two-Rowed		Heterozygous		Six-Rowed		Total
		No. Plants	Per cent	No. Plants	Per cent	No. Plants	Per cent	No. Plants
28801	1912	219	28.4	385	50.0	168	21.8	772
28901	1912	102	34.6	119	40.3	74	25.1	295
29001	1912	166	37.7	200	45.5	74	16.8	440
29101	1912	93	21.0	262	59.1	88	19.9	443
29201	1912	116	24.1	268	55.7	97	20.2	481
29301	1921	137	25.9	282	53.3	110	20.8	529
10901	1915	320	25.3	670	53.0	273	21.7	1263
11001	1915	376	26.8	698	49.8	327	23.3	1401
11101	1915	384	24.6	819	52.4	359	22.9	1562
11201	1915	211	25.2	427	51.1	198	23.7	836
11301	1915	228	24.6	473	51.1	224	24.2	925
11401	1915	190	24.7	385	50.1	193	25.1	768
11501	1915	184	24.5	383	51.0	184	24.5	751
Total Plants		2726		5371		2369		10,466
Average %.....			26.04		51.32		22.64	

The averages of Table XVII suggest the 1 : 2 : 1 ratio. Selected plants seeded the next year seemed to indicate that the plants whose lateral spikelets were beardless were heterozygous for the two-row vs. six-row allelomorphs. Six such plants gave again the three types in the F_3. Ten six-rowed plants all bred true to six-rows in the F_3 and F_4. The two-rowed plants also bred true to two-rows in the F_3 but were not carried farther.

In 1913 Tapp, a six-rowed bearded type was crossed on Rice, a two-rowed bearded type used in the other crosses. The F_1 gave an intermediate. Some of the lateral spikelets were fertile but smaller than the median spikelets and were without a fully developed floral appendage. The question arose as to whether the median and lateral seeds had the same genetic possibilities. To test this point the median and lateral spikelets of five F_1 plants were planted separately. The F_2 plants were pulled and divided into two-rowed, intermediate and six-rowed types. The *median* spikelets produced 411 two-rowed, 826 intermediate, and 421 six-rowed plants. The *lateral* spikelets produced 175 two-rowed, 407 intermediate, and 197 six-rowed plants which is approximately a ratio of 1 : 2 : 1 in each case.

Another cross was made between Excelsior (a six-rowed bearded, bald variety) and Rice barley. The bald vs. covered factor segregated independently of the two- vs. six-rowed phenomenon giving 25.7% bald and 74.3% covered plants. The six F_1 plants produced in the F_2 a total of 5686 plants of which 21.5% were two-rowed, 54.2% were intermediate, and 24.3% were six-rowed. The lateral spikelets of the F_1 in this cross were practically all fertile which was not the case with the other two- vs. six-rowed crosses. In the F_2, however, every variation occurred from complete sterility to complete fertility of the lateral spikelets. In the intermediates the lateral spikelets bore no awns, which made it comparatively easy to distinguish the types. In view of the fact that such complete fertility of the lateral spikelets occurred in the heterzygous types it is possible that the extracted two-rowed types might occasionally have one or more fertile lateral spikelets. If this proves to be the case it would account for the low percentage of two-rowed type and the high percentage of intermediate type as compared to a 1 : 2 : 1 ratio.

Two plants were found, in examining the 1385 plants of

six-rowed type, which had *sterile median* spikelets, making them a truly *four*-rowed variety. The offspring of these two plants will indicate next year whether this phenomenon was due to an injury or to an irregularity in gametic coupling.

Winter vs. Spring Type. In 1910 Rice barley (Wash. No. 912, C. I. 341) was crossed on Beardless barley (Wash. No. 873). These are both spring varieties. In 1911 six F_1 plants matured as spring barley. In the spring of 1912 the seed of these six plants were planted in six different rows. When harvest time came it was observed that many plants did not send up culms but tillered profusely and remained green like winter barley planted in the spring. The distribution of winter plants was uniform in all six rows. When the other plants were ripe, they were all pulled and the winter and spring plants counted separately. There were 689 winter plants and 2960 spring plants,—a ratio of 18.9% : 81.1%. A few of the winter plants were transplanted but none of them lived thru the severe winter of 1912 and 1913. It was thought that perhaps some of the later maturing spring plants might carry the winter factor as a recessive. Accordingly the seeds of 20 plants were seeded in the fall of 1912. All but a few plants winter-killed. Eight of those surviving were planted in the fall of 1913. These all lived thru the winter in excellent shape. Seventeen plants selected from the best four rows were planted in the fall of 1914 to test in the F_5 for yield and other qualities. Eight of these proved to be true winter, six were true spring type and three were heterozygous. In 1913 this cross was repeated, and in addition the Rice barley was crossed on two other varieties,—Tapp and Excelsior. These both mature grain when planted in the spring. The F_1 of all three crosses matured grain in 1914 from spring plantings. Six F_1 plants of Rice X Tapp were planted in the spring of 1915 and produced nothing but spring plants in the F_2. The Excelsior X Rice and Beardless X Rice both gave some winter plants in the F_2. The following table shows the results obtained:

TABLE XVIII.

Distribution of Winter and Spring Plants in F_2 Barley. Both Grandparents and the F_1 Were Spring Types.

Row No.	Year obtained	Male Parent	Female Parent	Winter		Spring		Total
				No. Plants	Per ct.	No. Plants	Per ct.	No. Plants
28801	1912	Rice	Beardless	205	21.0	772	79.0	977
28901	1912	Rice	Beardless	82	21.7	295	78.3	377
29001	1912	Rice	Beardless	91	17.1	440	82.9	531
29101	1912	Rice	Beardless	90	16.9	443	83.1	533
29201	1912	Rice	Beardless	101	17.4	481	82.6	582
29301	1912	Rice	Beardless	120	18.5	529	81.5	649
10901	1915	Beardless	Rice	319	20.1	1263	79.9	1582
11001	1915	Beardless	Rice	352	20.1	1401	79.9	1753
11101	1915	Beardless	Rice	383	19.7	1562	80.3	1945
11201	1915	Beardless	Rice	212	20.2	836	79.8	1048
11301	1915	Beardless	Rice	256	21.7	925	78.3	1181
11401	1915	Beardless	Rice	195	20.3	768	79.7	963
11601	1915	Excelsior	Rice	192	19.0	817	81.0	1009
11701	1915	Excelsior	Rice	155	15.0	875	85.0	1030
11801	1915	Excelsior	Rice	193	16.7	960	83.3	1153
11901	1915	Excelsior	Rice	154	13.9	957	86.1	1111
12001	1915	Excelsior	Rice	118	16.4	601	83.6	719
Total				3218	18.77	13925	81.23	17143

Fig 6.—Two F_2 plants of Excelsior X Rice, which show the difference between the spring and winter segregates. Less than one-half of the culm length of the spring type is shown.

The percentage of winter plants as shown in Table XVIII varies in the 17 F_2 rows recorded between 21.7% as the maximum and 13.9% as the minimum, with an average of 18.77% or almost exactly 3 plants in 16.

This ratio of 3 winter : 13 spring type is capable of factorial analysis if we assume as Dr. East has suggested, that the Rice barley is a true winter variety, WW that carries an inhibitor, II. The Beardless and Excelsior would then have the formula wwii. In the F_2 the types WWii and Wwii would be winter plants giving the ratio 3 : 13. If this be true the Wwii winter plants would produce 25% of wwii spring plants in the F_3, which spring plants would be identical with the Beardless and Excelsior parents. Also the spring type WwIi would produce 18.75% of winter plants in the F_3 just as the F_1 did. The spring type WWIi would produce 25% of winter plants in the F_3. We have not yet grown the F_3 from the F_2 winter plants but in 1916 the spring types of an F_2 of Rice X Beardless were planted. The seed of a single head only of each F_2 plant was used to avoid the possibility of mixing strains. From this planting 333 rows were obtained averaging 17.9 F_3 plants per row. Winter plants were found in 131 of the rows. This is 22.7 less than the 6 : 7 ratio which the above hypothesis calls for. When the F_3 plants were counted it was found that the percentage of winter type varied from 50% to 3.3% with 17.77% as the average. This is about 3% lower than we would expect, which is a very wide deviation for 2346 plants, the number under consideration. However, this may be due to seasonal variation, for 5 F_2 rows of Excelsior X Rice gave entirely different results in 1916 from those obtained the year before. In 1915 five F_2 rows produced an average of 16.2% winter plants. In 1916 five other F_2 rows of the same cross produced but an average of 4.2% winter type. The season of 1916 was much colder and wetter than that of 1915. Manifestly the cause of the winter habit must be investigated before we can interpret this irregularity. The writer is at the present time conducting experiments in both field and greenhouse with the object of isolating the climatic units that unlock the metabolic processes in winter grains which permit them to poduce seed.

FIG 7.—PHOTOGRAPH OF BLACK PARENT OAT TYPES.

1. Black has a side type of panicle and dark grain.

2. Black Tartarian is much like No. 1 but the grain is more slender and has an oily lustre.

3. Chinese Hulless has a tree or spreading panicle. The floral glumes are white but crosses of this variety on white hulled varieties indicates that it carried the factor for black floral glume color but that hullessness inhibits the color-development.

INHERITANCE IN OATS

Description of Characters Studied

White vs. Black Grain Color. These characters refer to the color of the hulls or floral glumes of the ripened grain. The white oats of Washington vary in color from a bright straw white to light yellow. The black varieties vary from black and reddish-brown to gray, depending somewhat upon the amount of sunshine and stage of maturity.

Side vs. Tree Type of Panicle. Side oats have a *unilateral* panicle, the flowers all hanging close to, and at one side of the main axis or peduncle. *Tree* oats are recognized by the even drooping of the pedicles of the flowers on all sides of the panicle similar to the branches of a tree.

Hulled vs. Hulless Character. The hulled oats retain the floral glumes when threshed as stiff, protective envelopes for the kernels. The hulless oats have large, flaring papery floral glumes which are not retained in threshing, thus leaving the seed freed of the hulls or floral glumes in the threshed grain.

Results After Hybridization

Black vs. White Grain Color. The color of the floral glumes of different varieties of oats at Pullman show marked contrast. The black oats are blacker than is common in most other sections of the United States and the yellow oats are almost white. It thus becomes very easy, under our conditions, to classify oats as black or white in a study of the inheritance of this phenomenon. In the work on color, ten different crosses have been made.

The following varieties have been used in the parentage:

1. **Canadian** (Wash. No. 742, C. I. No. 444) is a small, plump, white oat with spreading panicle, and stiff straw. Since its introduction in 1905, no variation in color has been noted.

2. **Large Hulless** (Wash. No. 680—C. I. No. 278) has white floral envelopes which do not adhere to the grain when threshed. It has a spreading panicle and normally bears five kernels per spikelet. This variety was obtained from the U. S. Dept. Agr. in 1904 and has bred true to color and hullessness since that time

3. **Palouse Wonder** (Wash. No. 748) is a commercial variety obtained locally in 1910. It is a white oat with spread-

ing type of panicle; it resembles Swedish Select but grows taller and the grain has thinner hulls.

4. **Regenerated Swedish Select** (Wash. No. 738) is a large white grained variety with spreading panicle and vigorous growth. The original seed was obtained from Garton Brothers, England, in 1908. It has shown no marked variation in color since that time.

5. **Sixty Day** (Wash. No. 661—C. I. No. 165) is a small, early maturing variety with spreading panicle and white grain which is slightly tinged with a cream yellow. It was obtained from the U. S. Dept. Agr. in 1904 and has always bred constant for color.

6. **Storm King** (Wash. No. 746) differs from the other white varieties in having the largest, plumpest grain and in having the compact side type of panicle. The original seed was obtained from a commercial sample in 1910 which was grown on the west side of the state in Whatcom county. It has bred true to color for the past five years.

7. **Black** (Wash. No. 665—C. I. No. 290) is a large, plump, dull black variety obtained from the U. S. Dept. Agr. in 1904. In the mature grain the floral glume or hull is always black. When fertilization fails to take place the floral glume often grows to full size but does not develop the black color. For this reason a superficial observation would indicate a lack of constancy in regard to color, but a careful investigation shows that the "white oats" appearing in a sample of this black variety are always sterile hulls.

8. **Black Tartarian** (Wash. No. 750) is similar to Black in color and panicle type, but it has a more slender grain which has an oily lustre.

9. **Chinese Hulless** (Wash. No. 686—C. I. No. 298) is much like the Large Hulless in general appearance, but may be distinguished from it by a brownish coloring of the palea. The two are fundamentally different, however, in their hereditary performance for, with regard to color, the Chinese Hulless breeds like a **black** oat while the Large Hulless breeds like a **white oat**.

The first six varieties named are white oats and the seventh and eighth are black. Altho the floral glumes of Chinese Hulless are white, the palea is brown, and it breeds like the other two black oats in respect to color. For this

reason, it is considered as a black oat, and all the hulless types in the F_2 separations which have the brown palea have been classified as black oats. The number of plants and percentage of each color found in the F_2 is given in the following table:

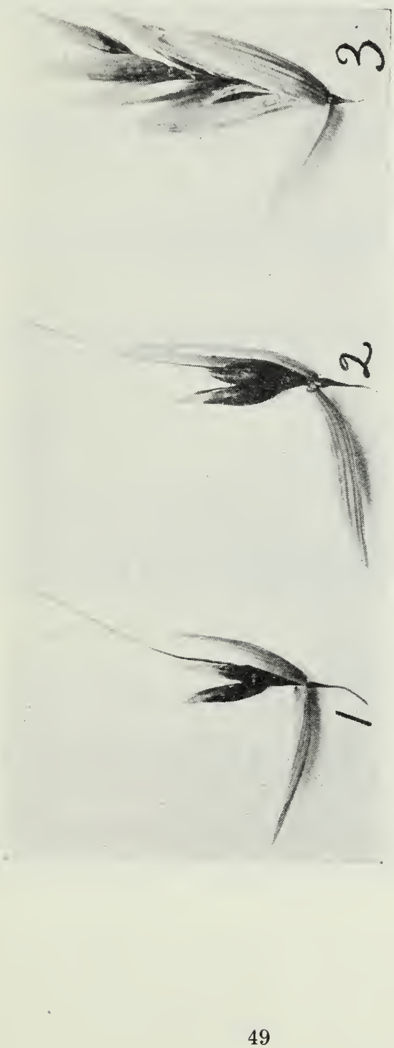

FIG. 8.—PHOTOGRAPH OF INDIVIDUAL SPIKELETS OF BLACK PARENT OAT TYPES.

1. Black Tartarian.
2. Black.
3. Chinese Hulless.

TABLE XIX.

Number of Plants Producing White and Black Oats in the F_2 from the Different Crosses of Black and White Varieties.

Row. No.	Varieties Crossed		White		Black		Total
	Male	Female	No. Plants	Per cent	No. plants	Per cent	No. Plants
11301	Storm King	Black Tartarian	122	26.2	344	73.8	466
11501	Reg. S. Select	Black Tartarian	63	33.2	127	66.8	190
11601	Reg. S. Select	Black Tartarian	52	24.3	162	75.7	214
11701	Black Tartarian	Reg. S. Select	3	20.0	12	80.0	15
11801	Black Tartarian	Reg. S. Select	10	33.3	20	66.7	30
11901	Black Oat	Reg. S. Select	189	23.9	601	76.1	790
12001	Black Oat	Reg. S. Select	46	21.2	171	78.8	217
12101	Black Oat	Reg. S. Select	22	23.2	73	76.8	95
12201	Black Oat	Sixty Day	95	21.0	358	79.0	453
12301	Black Oat	Sixty Day	270	25.9	772	74.1	1042
12401	Black Oat	Sixty Day	318	24.4	985	75.6	1303
12501	Black Oat	Sixty Day	80	22.2	280	77.8	360
12601	Black Oat	Sixty Day	58	19.8	235	80.2	293
12701	Black Oat	Sixty Day	126	22.3	440	77.7	566
12801	Black Oat	Sixty Day	33	25.4	97	74.6	130
12901	Black Oat	Sixty Day	5	29.4	12	70.6	17
13201	Black Oat	Sixty Day	7	21.9	25	78.1	32
14701	Black Oat	Palouse Wonder	168	21.5	613	78.5	781
14801	Black Oat	Palouse Wonder	155	23.7	500	76.3	655
14901	Black Oat	Palouse Wonder	107	23.5	350	76.5	457
15101	Black Oat	Palouse Wonder	165	23.0	551	77.0	716

TABLE XIX—(Continued).

Row No.	Varieties Crossed		White		Black		Total
	Male	Female	No. Plants	Per Cent	No. Plants	Per Cent	No. Plants
15201	Black Oat	Palouse Wonder	116	23.3	382	76.7	498
13501	Sixty Day	Chinese Hulless	428	26.6	1182	73.4	1610
13601	Sixty Day	Chinese Hulless	437	24.2	1371	75.8	1808
13701	Black Oat	Hulless	413	25.3	1222	74.7	1635
13801	Black Oat	Hulless	243	25.1	726	74.9	969
13901	Black Oat	Hulless	255	21.6	927	78.4	1182
14001	Black Oat	Hulless	284	24.8	863	75.2	1147
14101	Black Oat	Hulless	303	25.3	895	74.7	1198
14201	Black Oat	Hulless	288	24.0	911	76.0	1199
14301	Black Tartarian	Hulless	468	24.1	1474	75.9	1942
14401	Black Tartarian	Hulless	339	25.5	990	74.5	1329
14501	Black Tartarian	Hulless	82	23.2	272	76.8	354
14701	Canadian	Chinese Hulless	235	26.0	668	74.0	903
14801	Canadian	Chinese Hulless	173	25.6	503	74.4	676
15001	Storm King	Chinese Hulless	190	25.1	566	74.9	756
15101	Storm King	Chinese Hulless	162	32.4	338	67.6	500
15201	Storm King	Chinese Hulless	284	31.8	610	68.2	894
15301	Storm King	Chinese Hulless	212	24.9	638	75.1	850
15401	Storm King	Chinese Hulless	188	27.8	488	72.2	676
15501	Storm King	Chinese Hulless	212	27.1	570	72.9	782
Total			7406	24.9	22324	75.1	29730

The first five crosses, (numbers 11301 to 15201 inclusive), were made in 1910 and the last five (numbers 13501 to 15501) were made in 1913. The F_2 counts were made in 1912 and 1915, respectively.

A study of Table XIX shows in 41 different F_2 rows, including ten different crosses, that dark color is pretty uniformly dominant. An average of all the counts taken give almost an exact 3 : 1 ratio.

The unusual part in this work is the color behavior of the Hulless varieties. Evidently the factor that causes the floral glume to expand, elongate and remain wide-spread at maturity—(the characters that distinguish hulless varieties) inhibits the development of the dark color in the floral glumes, for in all the crosses there was not a single true hulless plant that developed black floral glumes. If it had not been for the brownish coloring of the palea the hulless hybrids which breed like black oats when crossed with white hulled varieties could not be distinguished from those that are genetically white.

Side vs. Tree Type of Panicle. This character of the oat presents several difficulties of classification. First, the stage of maturity affects to a marked extent the distinction between tree and side character. Second, there is considerable variation in the compactness of the parent strain of side oats and also much variation in the degree of spread of the tree oats. Furthermore, the different varieties in this test give different genetic results as the following table shows:

TABLE XX.

Side and Tree Oats Appearing in the F_2 from Four Different Crosses of Side and Tree Oats.

1912	Grandparents		Side Type		Tree Type		
Row No.	Male	Female	No. Plants	Per cent	Plants No.	Per cent	Total No. Plants
11501	Reg. S. Select	Black Tartarian	82	43.2	108	56.8	190
11601	Reg. S. Select	Black Tartarian	55	25.7	159	74.3	214
11701	Black Tartarian	Reg. S. Select	2	13.3	13	86.7	15
		Total..............	139	33.2	280	66.8	419
11801	Black Oat	Reg. S. Select	9	30.0	21	70.0	30
11901	Black Oat	Reg. S. Select	117	14.8	673	85.2	790
12001	Black Oat	Reg. S. Select	30	13.8	187	86.2	217
12101	Black Oat	Reg. S. Select	7	7.4	88	92.6	95
		Total..............	163	14.4	969	85.6	1132
12201	Black Oat	Sixty Day	99	21.9	354	78.1	453
12301	Black Oat	Sixty Day	169	16.2	873	83.8	1042
12401	Black Oat	Sixty Day	150	11.5	1153	88.5	1303
12501	Black Oat	Sixty Day	59	16.4	301	83.6	360
12601	Black Oat	Sixty Day	48	16.4	245	83.6	293
12701	Black Oat	Sixty Day	80	14.1	286	85.9	566
12801	Black Oat	Sixty Day	24	18.5	106	81.5	130
12901	Black Oat	Sixty Day	3	17.6	14	82.4	17
13201	Black Oat	Sixty Day	9	28.1	23	71.9	32
		Total..............	641	15.3	3555	84.7	4196
14701	Black Oat	Palouse Wonder	40	5.1	741	94.9	781
14801	Black Oat	Palouse Wonder	35	5.3	620	94.7	655
14901	Black Oat	Palouse Wonder	28	6.1	429	93.9	457
15101	Black Oat	Palouse Wonder	36	5.0	680	95.0	716
15201	Black Oat	Palouse Wonder	31	6.2	467	93.8	498
		Total..............	170	5.5	2937	94.5	3107

Note—All intermediates were classified as "Tree Oats."

Black Tartarian X Swedish Select gives 33.2% of F_2 side oats.

Black X Regenerated Swedish Select gives 14.4% of F_2 side oats.

Black X Sixty Day gives 15.3% of side oats in F_2.

Black X Palouse Wonder gives 5.5% of side oats in the F_2.

Evidently Black Tartarian has a greater potential for the side character than Black since it gives more than twice as many side oats in the F_2 when crossed with the same tree oat, namely, Regenerated Swedish Select. On the other hand Palouse Wonder produces almost three times as many plants in the F_2 which show the tree character, as either

TABLe XXI.
Black X Sixty Day in the Third Generation.

1913 Row No.	Type Panicle F_2 Parent Plant	Side Type		Tree Type		Total
		No. Plants	Per cent	No. Plants	Per cent	
5701	Tree	518	51.0	498	49.0	1016
5801	Tree	...	...	642	100	642
5901	Tree	168	31.2	371	68.8	539
6001	Side	909	100	...	...	909
6101	Side	...	100	...	...	
6201	Side	392	39.3	606	60.7	998
6301	Side	247	100	...	...	247
6401	Side	110	100	...	...	110
6501	Side	918	100	...	...	918
6601	Side	1138	100	...	...	1138
6701	Side	448	100	...	...	448
6801	Side	182	100	...	...	182
6901	Tree	...		437	100	437
7001	Tree	352	42.7	473	57.3	825
7101	Tree	190	49.1	197	50.9	387
7201	Tree	260	21.4	956	78.6	1216
7301	Tree	...		...	100	
7401	Tree	...		614	100	614
7501	Tree	All intermediate		...	...	
7601	Tree	153	24.4	449	74.6	602
7701	Tree	...			100	
7801	Tree	115	26.3	323	73.7	438
7901	Tree	248	22.0	878	78.0	1126
8001	Tree	...		...	100	
8101	Tree	86	19.3	359	80.7	445
8201	Tree	125	11.4	969	88.6	1094
8301	Tree	...		179	100	179
8401	Tree	...		443	100	443
8501	Tree	283	26.9	768	73.1	1051
8601	Tree	188	28.0	483	72.0	671
8701	Side	533	100	...	...	533

Sixty Day or Regenerated Swedish Select when crossed on Black.

An F_2 family (13201 of Table XX) of Black X Sixty Day containing 9 plants of side type and 22 classed as tree oats was grown in the F_3.

The progeny of these 31 F_2 plants are classified in Table XXI.

Each F_2 plant classified as Side Type bred true except No. 6201 which proved to be heterozygous. The number which bred true to either tree or side type would lead one to assume this character to be a monohybrid, but a study of the intermediates presents some serious difficulties for any such hypothesis. Row No. 7501 bred true to an *intermediate* condition, five selections from this row bred true in the F_4 and 14 selections from these five rows in turn bred true to the intermediate condition in the F_5. Selections from Row 7701 (which was classified as 100% tree type in F_3) gave peculiar results. Two selected plants produced again nothing but tree oats. Three other selections produced only the *intermediate* type in F_4. Just why plants which were typically tree type and whose parent was a tree oat should suddenly produce pure intermediate type of panicle is puzzling to say the least. Three plants of side type from Row No. 7001 bred true in the F_4 but from these, one of seven selections produced a pure intermediate row in F_5. This is just as inexplicable as the former case. In the first instance an extracted tree oat plant produced nothing but true intermediates. In the second instance an extracted side oat plant produced nothing but true intermediates. These intermediates resemble the F_1's but unlike the F_1's they breed true, while the F_1's give the irregular ratios of side and tree type shown in Table XX. This irregularity of plants, heterozygous for panicle type in the F_2, produced irregular ratios in the F_3, as shown in Table XXI in which the percentage of side type varies from 51% to 11.4%. There is little liklihood that this is a mere chance variation for the rows were grown side by side and there were more than a thousand plants in each row in which these extremes occurred. The difference could easily be seen in the field before the oats were ripe.

Five plants of tree type were selected from Row No. 7001. Three of them bred true but the other two proved to be heterozygous for the panicle character; one produced 433

plants—28.6% of which were side type. The other produced 388 plants of which 19.6% were side type.

These irregularities could not be due to natural crossing for oats seldom, if ever, cross in nature. For the past five years more than one hundred selections of oats have been grown in the same field side by side in rows only 18 inches apart. The seed each year has been taken from the bulk lot of the crop previous—and very rarely have aberrant types occurred.

Hulled vs. Hulless Character. *Hulled* oats have a floral glume that acts as a protection and encloses the kernel com-

FIG. 9.—A DISSECTED SPIKELET OF CHINESE HULLESS OATS.
1. Outer glume.
2. Floral glume.
3. Grain.
4. Palae.

The grain has taken dark in the picture, but in reality it is amber—the color of the "meat" of common oats. The palea is brown. All other parts should be straw colored.

pletely. Uusually there are one to three grains in each spikelet of hulled oats. Practically all of the commercial oats are of this type. The *Hulless* types differ in floral glumes, paleae, and spikelets. The floral glume is a loose,

angled covering with a prominent mid-rib, and does not adhere to the kernel as the hulls of common oats do. The palea is an elongated, tongued-shaped affair that holds the grain so loosely that it shatters badly when ripe. The rachilla in the spikelet is elongated and bears four to six fertile flowers instead of one to three as in hulled oats.

In 1910 several crosses were made between Black (Wash. No. 665) and Hulless oats (Wash. No. 680) and between

TABLE XXII.

Number of Hulled and Hulless Oat Plants Occurring in the F_2 in Eleven Families Representing Two Different Crosses.

1912 Row No.	Hulled		Hulless		Total Plants
	No. Plants	Per cent	No. Plants	Per cent	
10001	465	59.4	318	40.6	783
10101	370	67.4	179	32.6	549
10201	339	41.7	473	58.3	812
10401	101	42.4	137	57.6	238
10501	41	29.5	98	70.5	139
10601	133	28.9	327	71.1	460
10701	25	54.3	21	45.7	46
Total...	1474	48.7	1553	51.3	3027
15301	110	87.3	16	12.7	126
15501	229	83.6	45	16.4	274
15601	48	69.6	21	30.4	69
15701	574	73.9	203	26.1	777
Total...	961	77.1	285	22.9	1246

Note—Numbers 10001 to 10601 are from crosses of Palouse Wonder and Chinese Hulless. Number 10701 is the reciprocal—Chinese Hulless X Palouse Wonder. Number 15301 is a cross of Black Oat X Hulless. The last three are reciprocal—Hulless X Black Oat.

Palouse Wonder (Wash. No. 748) and Chinese Hulless (Wash. No. 686). In 1911 the resulting F_1 plants in each cross had both *hulled* and *hulless* oats on the same panicle. The hulled oats appeared only on the lower spikelets and were confined for the most part to the secondary and tertiary oats of the spikelet, the primary oat being hulless. The F_2 produced pure hulled plants, pure hulless plants and plants bearing both hulled and hulless oats. In the rush of harvest work these types were separated arbitrarily into two groups putting the heterozygous types into the group which it resembled most. The results indicate that neither factor was clearly dominant. Table XXII gives the counts as they were made in the field.

The average ratio of hulled to hulless plants from the seven families of Palouse Wonder (Wash. No. 748) X Chinese Hulless (Wash. No. 686) was 48.7 : 51.3. This indicates an intermediate about half-way between hulled and hulless for the heterozygous types. As was mentioned above, the separation was made arbitrarily into hulled and hulless, according to the type any given plant most nearly resembled. The average ratio of the four F_2 families of Black (Wash. No. 665) X Hulless (Wash. No. 680) gave the ratio 77.1 hulled : 22.9 hulless. This shows a decided dominance of the hulled character, and indicates that the two crosses are not analogous. Five F_2 plants of Palouse Wonder X Chinese Hulless of hulless type were selected for planting from row 10501 of Table XXII. Four of them bred true to the hulless character but the fifth produced 106 hulled and 293 hulless plants in the F_3. In this separation the intermediate plants were classified as hulless. In like manner five F_2 plants of Black X Hulless of hulless type were selected from row 15301 of Table XXII. Two bred true to the hulless character in the F_3 and F_4, one produced 66 hulled and 213 hulless F_3 plants (the intermediates were classified as hulless), but the other two produced 770 F_3 plants of which 74% were hulless and 26% were intermediates; that is, both hulled and hulless oats appeared on the same plant, *but there were no entirely hulled plants.* Moreover one of the intetrmediate F_3 plants produced 100% of intermediate plants in the F_4.

In 1914 several other crosses were made between these two hulless varieties and different varieties of common hulled oats. In 1915 the F_1's were uniformly alike in respect to the character of adhering hulls. The primary oats were hulless thruout, and toward the top of the panicle the second, third fourth and fifth oats in the spikelets were also hulless. The lower spikelets bore only 3 or 4 oats and all but the first were hulled. The F_2 of these crosses were grown in 1915 and the plants were separated into Hulled, Intermediate and Hulless types. The following table gives the number and per cent of plants of each type found in the different crosses:

TABLE XXIII.

Hulled, Intermediate, and Hulless Plants Occurring in Twenty Families, Representig Six Different F_2 Crosses.

1915 Row No.	Hulled		Heterozygous		Hulless		Total No. Plants
	No. Plants	Per cent	No. Plants	Per cent	No. Plants	Per cent	
F_2 Sixty Day (Wash. No. 661) X Hulless (Wash. No. 680.)							
13301	408	26.6	756	49.4	367	24.4	1531
13401	232	26.6	425	48.6	217	24.8	874
Total	640	26.6	1181	49.1	584	24.3	2405
F_2 Sixty Day (Wash. No. 661) X Chinese Hulless (Wash. No. 686)							
13501	425	26.4	978	60.7	207	12.9	1610
13601	478	26.4	1178	65.2	152	8.4	1808
Total	903	26.4	2156	63.1	359	10.5	3418
F_2 Black (Wash. No. 665) X Hulless (Wash. No. 680).							
13701	397	24.3	784	47.9	454	27.8	1635
13801	260	26.8	398	41.1	311	32.1	969
13901	345	29.2	726	61.4	111	9.4	1182
14001	310	27.0	723	63.0	114	10.0	1147
14101	313	26.1	431	36.0	454	37.9	1198
14201	318	26.5	763	63.6	118	9.9	1199
Total	1943	26.5	3825	52.2	1562	21.3	7330
F_2 Black Tartarian (Wash. No. 750) X Hulless (Wash. No. 680).							
14301	550	28.3	1235	63.6	157	8.1	1942
14401	396	29.8	746	56.1	187	14.1	1329
14501	94	26.6	223	63.0	37	10.4	354
14601	73	28.5	154	60.2	29	11.3	256
Total	1113	28.7	2358	60.7	410	10.6	3881
F_2 Canadian (Wash. No. 742) X Chinese Hulless (Wash. No. 686).							
14701	227	25.1	615	68.1	61	6.8	903
14801	198	29.3	424	62.7	54	8.0	676
Total	425	26.9	1039	65.8	115	7.3	1579
F_2 Storm King (Wash. No. 746) X Chinese Hulless (Wash. No. 686).							
15001	179	23.7	479	63.3	98	13.0	756
15101	173	29.0	251	42.1	172	28.9	596
15201	240	26.8	465	52.0	189	21.1	894
15301	225	26.5	497	58.5	128	15.1	850
15401	139	20.6	436	64.5	101	14.9	676
15501	223	28.5	441	56.4	118	15.1	782
Total	1179	25.9	2569	56.4	806	17.7	4554
Wash. No.			SUMMARY				
661/680	640	26.6	1181	49.1	584	24.3	2405
661/686	903	26.4	2156	63.1	359	10.5	3418
665/680	1943	26.5	3825	52.2	1562	21.3	7330
750/680	1113	28.7	2358	60.7	410	10.6	3881
742/686	425	26.9	1039	65.8	115	7.3	1579
746/686	1179	25.9	2569	56.4	806	17.7	4554
Total	6203	26.8	13128	56.7	3836	16.6	23167

The summary of Table XXIII shows some interesting and significant ratios. The percentage of hulled type suggests a simple Mendelian recessive altho in every case there are a few too many hulled plants. The percentage of Hulless plants is not only very irregular in the different crosses but is also irregular in the different families within the same cross with the exception of the two families of Sixty Day X Hulless, which gave a ratio approaching 1 : 2 : 1. The intermediate types showed great variation. Plants could be found with only one or two spikelets that showed the hulless character. Others could be found that showed the hulled character in only one or two spikelets, and plants were obtained with every degree of hullessness between these extremes. However, most of the intermdiates produced more than half hulled oats. A curve fitted to these intermediate variations in Black Tartarian X Hulless shows larger numbers at either extreme and few numbers showing per cents of hulled oats ranging from 30 to 50. This is just the opposite of what we would expect if the hulless character was caused by a single Mendelian unit which produced an intermediate in the F_1.

A proper analysis of the resulting F_3 should throw some light on the above apparent irregularities.

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STATE COLLEGE OF WASHINGTON

AGRICULTURAL EXPERIMENT STATION

PULLMAN, WASHINGTON.

DIRECTOR'S OFFICE

Twenty-sixth Annual Report

For the Year Ending June 30, 1916

BULLETIN NO. 136

January, 1917

All Bulletins of this Station sent free to citizens of the State on application to Director

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*Died August 18, 1916.

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LETTER OF TRANSMITTAL

Pullman, Washington, January 18, 1917

Honorable Ernest Lister, Governor,
Olympia, Washington.

Sir:

I have the honor to submit herewith the Twenty-Sixth Annual Report of the State Agricultural Experiment Station covering the work of this Station for the year ending June 30, 1916.

Very respectfully,
IRA D. CARDIFF,
Director.

Twenty-sixth Annual Report, Washington Agricultural Experiment Station

ELTON FULMER

It is with deep regret that the passing of Professor Fulmer must be reported. Professor Fulmer was the senior member of the Station Staff and was actively engaged in his duties as State Chemist when he met an untimely death by a railroad accident near Cheney, Washington, on February 20, 1916.

Professor Elton Fulmer became connected with the Station in 1893, less than two years after its organization. He was the first State Chemist, which position he retained until his death. In 1909 he was made Dean of the Faculty of the State College. The last three months of the fiscal year 1912-1913 he served as acting director of the Experiment Station. During his connection with the Station he was author of the following bulletins, embodying results of his work:

No. 9—Sugar Beets
No. 13—Washington Soils
No. 15—Sugar Beets in Washington
No. 23—Notes Concerning Nitrogen and Humus Content of Soils
No. 26—Sugar Beets, 1895-6
No. 31—Sugar Beets in the Yakima Valley
No. 55—Washington Soils
No. 67—Some Notes Concerning Halphen's Test
No. 98—Commercial Fertilizers
No. 110—Commercial Fertilizers
Popular No. 37—Commercial Fertilizers

During the same period he also contributed numerous scientific articles to the technical journals of the country. Thruout his long career as chemist of the Station, his services were of the greatest aid to the State in its numerous attempts at enforcement of pure food and other regulatory measures. His loss is keenly felt by the institution and the State.

CHANGES IN STAFF

Changes in staff for the fiscal year 1915-16 include the following:

George A. Olson became chemist of the Station and State Chemist, vice Elton Fulmer, whose death is noted elsewhere in this report; C. H. Shuele, Assistant Chemist, vice A. L. Sherman, resigned.

Additions to the staff were J. S. Caldwell as plant physiologist of the Experiment Station, and M. B. Boissevain as assistant in farm crops in charge of the Waterville substation.

INVESTIGATIONS

DIVISION OF AGRICULTURE

Animal Husbandry.

During the past year feeding experiments with swine in this Department have been conducted upon four projects.

Tankage vs. Blatchford's Pig Meal as a Protein Supplement to Barley.

Seventy-three newly weaned pigs were divided into three groups and placed in dry lot, pea and oat pasture, and alfalfa pasture, respectively. Each group received a ration of 95% rolled barley and 5% pig meal, fed in a self-feeder. After 24 days of feeding as described, the pigs failed to make economical gains and were placed on a ration of 92% rolled barley and 8% (meat meal) tankage, sixty per cent grade. The other conditions were the same.

On changing the dry-lot group to tankage, the daily gain per head was practically doubled. The amount of concentrates per 100 pounds of gain was reduced from 550 pounds to 393.1 pounds and the cost of 100 pounds of gain was also reduced from $7.22 to $5.30.

The pea and oat group increased their gain from .35 pounds to .69 pounds per head daily and reduced the cost from $5.37 to $4.40 per 100 pounds of gain. The amount of concentrates per 100 pounds of gain was reduced from 409.2 pounds to 326.2 pounds.

The alfalfa group presented the most striking difference. They increased their daily gain from .310 pounds to .836 pounds per head and reduced the amount of concentrates from 523.8 to 373.3 pounds per 100 pounds of gain. The cost was also reduced from $6.87 to $5.10 per 100 pounds of gain. This test would indicate a notable superiority of meat-meal tankage as compared with pig meal.

The Relation of Poor vs. Proper Wintering of Pigs to Subsequent Development and Returns of Gain.

Twenty-four hogs were employed. The poorly wintered hogs had been wintered around straw stacks and in snow-clad stubble fields, with no grain. The properly wintered hogs had been fed a growing ration through the winter.

During the test, the hogs were fed three parts by weight of rolled barley and one part by weight of shorts.

The results showed that the poor wintering of the pigs had not destroyed their ability to grow and fatten, but had limited their capacities for food consumption and delayed their finishing.

Fattening Value of Wheat vs. Barley.

Results of this experiment with 15 pigs showed that 100 pounds of gain was made with 447 pounds of wheat and 552 pounds of barley. If barley is taken as 100, then wheat is worth 123, or with barley at $25 per ton, wheat is worth $30.75 per ton for fattening barrows.

Determination of the Cost of Gains with Self-fed Swine on Alfalfa Pasture.

Twelve pigs were fed for seventy-four days upon a ration of 90% rolled barley and 10% tankage from a self-feeder. Salt and minerals were also in a separate compartment of the grain feeder. Skim milk to the extent of 100 pounds was fed daily. Results indicate an average cost of $5.50 per hundred pounds of gain, not considering the value of the pasture.

Dairy Husbandry.

The work of the division has been confined during this year to two projects: one on silage feeding, and the other a test of the relation of size of cows to milk production.

Silage Feeding.

Tests were conducted during the year upon four kinds of silage, namely, corn, peas and oats, clover, and wheat.

The experiment was still in progress at the end of the year and the results of the various feeds on milk production are not yet available. However, the peas and oats silage compared favorably with corn, keeping in excellent condition and being relished and eaten as readily as corn by the cows. Wheat silage, however, is apparently slightly inferior to corn, both from the standpoint of milk production and the way the feed is relished by the cow. Clover silage was also fed in comparison with the other silage feeds and it showed little or no difference in its effect upon production. Cows failed to eat it quite so well at first, but upon becoming accustomed to it apparently ate it with as much relish as the corn silage.

Economy of Production from Large vs. Small Cows.

Work is being continued on this project as indicated in the 25th report, the project not having been conducted long enough as yet to warrant general conclusions.

Farm Crops.

June 30th is an unfortunate time at which to make a report upon farm crops work, since it is in the midst of a growing season. It, therefore, becomes necessary to report the results of the 1915 crop and the plantings for 1916, deferring a report upon the results of the latter until the succeeding year. The investigations of the Division are being conducted under six projects.

Inheritance Studies.

Inheritance studies are being conducted with wheat, oats, barley and rye, with a view to determining the behavior in wheat of characters connected with drought resistance, resistance to smut, head length, pubescence, yield, gluten content, beardlessness, grain color, and spring and winter factors. In barley the behavior of the following characters are being studied: Sterility of lateral spikelets, beardlessness, hullessness, spring and winter habits and stiffness of straw. With oats, the characters studied are glume color, panicle shape, date of maturity and hullessness. With rye, studies are being

Fig. II. Reversion to winter type in second generation barleys.

Rice barley and **beardless** barley are true spring varieties. A hybrid seed obtained by crossing these two barleys produced a spring plant. The grain of this plant seeded in the spring produced 18.75% of winter plants like No. 1, and 81.75% of spring plants like No. 2. The grains which produced the above plants came from the same head, were planted the same day and grew side by side.

made with reference to beard vs. beardlessness and winter and spring factors. Attempts are being made to arrive at the cause of smut resistance and the cause of hullessness of oats.

This project is one dealing with fundamental principles of science. The value of results obtained may not always be apparent on the surface; however, the large mass of data procured in the inheritance investigations eventually will prove of tremendous value as a foundation for marked improvement in our cereal crops. The project has been continued a number of years and the results obtained are responsible for the production of many of our better varieties of wheat in the Northwest. A detailed report of this work (Bulletin 135) is in press.

Variety Testing.

The testing of varieties has to do not only with those products of our own breeding nursery, but any variety of promise which may come to the attention of the Station. The work for the year ending June 30th, 1916, of course includes the results of the 1915 crop only. The work was conducted with wheat, oats, barley, corn and other crops.

Wheat.

In addition to the testing of 100 varieties in the nursery, field tests for winter wheat were conducted in duplicate in 40th acre plots. The following table gives the average yield of each variety (grown upon ground which was in corn the previous year) in duplicate plots for 1915, also average yield for 1914-15:

TABLE I.

Rank	Wash. No.	Name of Variety	Yield per Acre in bu. 1915	Yield per Acre in bu., avg. 1914-1915
1	597	Triplet	44.85	49.37
2	601	Turkey/Bluestem X White Track/Little Club	48.85	47.22
3	598	Triplet's Sister	43.15	46.37
4	590	Hybrid 143	45.80	44.50
5	592	Hybrid 128	42.75	43.72
6	546	Turkey X Bluestem	39.55	43.12
7	594	Hybrid 60	44.65	42.92
8	587	Turkey X Winter Fife	46.55	42.52
9	600	Winter Fife/Little Club X White Track/Little Club	42.40	42.45
10	541	Turkey X Bluestem	39.75	41.77
11	500	Little Club	39.70	41.70
12	599	Hybrid 150 X Turkey	37.45	41.37
13	591	Hybrid 108	42.75	41.32
14	536	Turkey X Bluestem	41.05	41.07
15	593	Hybrid 123	38.80	40.35
16	326	Turkey Red	35.95	38.77
17	270	Red Russian	34.80	38.75
18	595	Hybrid 150	37.10	38.70
19	588	Turkey X Winter Fife	39.75	38.37
20	626	Winter Fife/Little Club X Winter Fife/Turkey	37.95	....
21	371	Winter Fife	37.60	37.70
22	627	Turkey/Little Club X Turkey	36.50	.....
23	351	Forty Fold	33.25	33.97

It will be noted that Triplet, a composite hybrid, developed at this Station, gave the highest yield for a period of two years. Triplet grades Fife yet outyields this variety by 11.67 bu. per acre and Forty Fold by 15.4 bu. per acre. It outyields the standard Red Russian 10.62 bu. per acre and will normally bring 3 to 5 cents per bushel more on the local markets.

The following table gives yields of spring wheat varieties which were tested in a manner similar to the winter wheats:

TABLE II.

Rank	Wash. No.	Name of Variety	Yield per Acre in bu. 1915	Yield per Acre in bu., avg. 1914-1915
1	622	Chul X Bluestem	35.19	32.79
2	421	Red Chaff	27.58	32.29
3	624	Bluestem X Chul	32.53	32.21
4	501	Ritzville Bluestem	27.20	31.70
5	516	Red Bluestem	27.01	31.00
6	620	Kubanka X Bluestem	33.67	30.38
7	362	Sprague Bluestem	27.39	30.14
8	623	Bluestem X Chul	33.10	30.10
9	576	Marquis	31.38	29.34
10	265	Red Allen	25.11	29.11
11	621	Kubanka X Bluestem	31.01	28.80
12	500	Little Club	28.08	27.09
13	590	Hybrid 143	23.20	26.20

It will be noted that Chul X Bluestem cross, developed at this Station, gives the highest yield.

Oats.

In the field variety tests of oats, Sixty Day oats gave the highest yield for 1915, but as an average for two years, Abundance gave the highest yield, with Banner second and Swedish a very close third. These field tests also agree with the tests of the same varieties in the nursery.

Results of oat variety tests for the Station for the past three years, have been published in General Bulletin No. 129. There are, at the present time, 120 varieties of oats under test.

Barley.

The Tapp Winter Barley gave the highest yield for an average of two years, 1914-15 (64.1 bushels per acre). Beldi gave the highest yield of spring barley in 1915. The Blue Barley, however, gave the highest yield of spring barley (64.77 bushels per acre), for an average of the two years, 1914-15. Twenty-seven varieties of barley are under test.

Corn.

The work with corn in this project consists of ear-row tests with Windus White and Thayer Yellow corn, a rate of seeding test with corn, and a variety test consisting of twelve varieties. Each ear-row test contained 25 ears

planted in separate duplicate rows. Different individual ears of the Windus corn showed a variation of 6.43 to 18.64 bushels per acre (abnormally dry year at Pullman) and the Thayer Yellow gave a variation of 20.0 to 29.64 bushels per acre.

The Dakota White Flint gave the largest yield for a one-year test. Both the varieties, Windus White and Thayer Yellow, have been made purer by selection. A number of plants were selfed with the view of reducing them to a more nearly homozygous condition.

Peas.

The variety test of field peas is being continued. The following table gives the 1915 yields tested on 1/20 acre plots:

TABLE III.

Rank	Name of Variety	Yield per Acre in Bushels
1	Canada	28.50
2	Abyssinia	27.00
3	Bangalia	26.16
4	Amaroti	22.66
5	Blue Bell	21.66
6	Kaiser	21.00

Miscellaneous Crop Experiments.

Other crops under variety test are rye, sorgo, soy beans and flax; also combinations of grain mixture tests of wheat, oats, barley and peas.

Environmental Tests.

The environmental experiment conducted in co-operation with the U. S. Department of Agriculture is being continued. The 1915 result is given in the following table:

TABLE IV.

Name of Variety	Source of Seed	Bushels per Acre
Haynes Bluestem	Pullman, Wash.	38.81
" "	Williston, N. D.	39.35
" "	St. Paul, Minn.	37.78
Spring Emmer	Pullman, Wash.	70.96
" "	Highmore, S. D.	70.64
" "	Bozeman, Mont.	64.83

Ritzville Experiments.
(Dry Land)

The variety tests at Ritzville, under a 12-inch rainfall, are being continued. In 1915 Hybrid 143 gave the highest

yield (54.4 bushels per acre) of the winter varieties of wheat. Early Baart gave the highest yield of the spring wheat (52.6 bushels per acre). Blue Barley gave the highest yield for barley (82.5 bushels per acre). Sixty Day was the highest yielding variety of oats (76.25 bushels per acre). All cereal crops grown at Ritzville were upon summer-fallow ground.

Increase and Distribution of Seed.

During the year, 42,122 pounds of new and improved seed were distributed to reliable farmers for testing. This seed was sent out only after each variety had been subjected for a number of years to rigorous testing in the nursery and field of the Station farm. The improved seed has been sent to thirty-one counties in the state and some to neighboring states. This seed is not distributed in a promiscuous or wholesale fashion, but sold, and only to such farmers as can be relied upon to follow directions and report results to the Station.

Forage Crops.

Breeding and selecting forage crops, especially alfalfa and clover, is in progress, but the work had to be greatly restricted during the year on account of lack of funds. Little progress, therefore, was made.

Variety tests of root crops—turnips, carrots, mangels, rutabagas, etc., are being carried on.

Investigations are also in progress with a view to determining the best cultural practices in the growing of alfalfa, red clover, sweet clover and other forage crops for seed production. Soy beans are being tested but with unsatisfactory results.

Inoculation of Legumes.

The work of supplying pure cultures for the inoculation of alfalfa, clover, field peas, vetch and other legumes, has been conducted during the year in co-operation with the Department of Botany of the College. Inoculation material has been sent to numerous farmers in almost every county of the state. This material is sent out in tin packages of soil previously sterilized and inoculated with a pure culture of the organism desired. The farmer is furnished with a blank for reporting results of the use of the pure cultures in order to give the Station information in regard to the amount of benefit derived from the distribution of these cultures.

Crop Rotation.

The rotation and cultural experiments on field 6, which have been running for 15 years, give the following results:

The plot which has grown *corn* and *winter wheat* alternate years has given the greatest total yield of grain in 15 years, and ranked among the highest in yield of winter wheat in 1915 (45 bus. per acre).

The plot giving the next highest total grain yield in 15 years has been cropped to winter wheat annually, but manure has been plowed under each fall at the rate of 10 tons per acre. (In 1915, however, the yield was mediocre, 29 bus., and the grain somewhat burnt.)

The plot giving the largest yield (46 bus. per acre) in 1915, was on a five-year rotation as follows: clover and timothy, 1911 and 1812; oats and peas (10 tons manure added per acre), 1913; corn, 1914; wheat, 1915.

In general the plots in rotation gave larger yields than those growing wheat continuously, either annually or in alternation with summer fallow.

Soil Physics.

Soil Moisture Studies.

Soil moisture investigations have, as previously noted, been conducted under irrigated conditions at Grandview, under dry-land conditions (12 in. rainfall) at Ritzville, and under sub-humid conditions (23 inches rainfall) at Pullman. The relative moisture conditions under different methods of tillage are being studied. In this work especial attention is given to the relation of moisture to nitrogen supply, since in Eastern Washington nitrogen is one of the important limiting factors in soil fertility.

Results thus far obtained indicate that early spring tillage gives a higher nitrate content than late spring tillage, and also that intertilled crops like corn, show a higher nitrate development than untilled cereal crops. These field experiments are checked by pot cultures under controlled conditions in the greenhouse. The effect of previous crops upon moisture content and fertility of soil is being studied.

Preliminary results in connection with some of the investigations have been published during the year in Bulletin No. 123, "Time and Method of Tillage on the Yield and Comparative Cost of Production of Wheat in the Palouse Region of Eastern Washington."

The Grandview sub-station work dealt with the effect of varying methods of cultivation and various amounts of water upon the yield of corn, the time of cultivation upon the yield of alfalfa, and the fluctuation of the water table.

The results indicate that 12 to 16 inches of water is the best amount to apply for corn, under conditions of the Grandview sub-station, while at the same location the highest yield of alfalfa was obtained by spring-tooth cultivation after each cutting.

At the Main Station, work was conducted upon the relation of various cover crops to nitrification. Nitrification is affected not only by tillage, but by other soil treatment, such as rotation of crops, green manuring, and the application of barnyard manure.

For the past three years the Experiment Station orchard has grown different cover crops, sown in the fall and plowed under the following spring. This Division, in co-operation with the Horticultural Division, has studied the effects of these cover crops on the rate of nitrification.

The results indicate that the legumes are more easily nitrified than the cereals, and that the decomposition is such that they maintain a higher nitrate content in the soil.

The relation of crop residues to future crop yields is also being worked upon both in pot cultures in the greenhouse, and under field conditions.

The effect of the previous crop on the yield and quality of wheat is being given careful study. Winter wheat gave highest yield when grown upon land cropped in beans the previous season. The crops standing next in order of wheat yield were: peas, potatoes, corn, summer fallow, carrots, barley, oats, winter wheat. The winter wheat having the highest nitrogen content, was grown upon summer-fallow ground. That having next highest was grown upon ground which produced potatoes the previous season and following the order of the highest nitrogen content in wheat, the previous crops were: carrots, beans, peas, corn, winter wheat, barley, oats.

These results indicate that legumes and intertilled crops are followed by a higher yield and nitrogen content of wheat than are the cereals.

The effect of limiting one essential plant food upon the yield and water requirements of crops has also been studied for several years and was continued during the past season.

DIVISION OF BOTANY

One of the important activities of this division has to do with the handling of a large number of miscellaneous requests for information and assistance by the farmers of the state, especially for identification of plant diseases, weeds, seeds, and other plant products, and the bacteriological examination of milk, butter, cheese and water. During the year a large amount of work of this nature has been handled by the department. The work of the department has been facilitated materially by the acquisition of ten acres of land for a pathologium devoted exclusively to the study of plant diseases.

Bacteriology.

Metabolism of Tubercle Bacterium.

Work upon this project has progressed satisfactorily by the use of improved media upon which different strains of *Bacterium tuberculosis* have been grown successfully. Improved methods of isolation have also been perfected. Marked progress has been made in the study of the metabolism of the organisms from the standpoint of producing tuberculins free from heterogeneous albuminoids. A preliminary report of the work was published in May as Bulletin No. 132 of the Station and the work is being continued with very promising prospects.

Pathology.

Tomato Blight and Related Diseases.

It has been found that the casual organism of tomato blight is a species of Rhizoctonia and studies have been made with reference to the exact relation and degree of susceptibility of various varieties of tomato to this fungus; also the relation of the fungus to other hosts,—beans, cucumbers, peas, peppers, potatoes, strawberries, and others.

Attempts were also made to connect Fusarium with tomato blight as previously suggested in Washington Station Bulletin No. 115, but without success.

Recent information has been obtained indicating that soil conditions exercise a marked influence upon the behavior of Rhizoctonia with reference to infection of the hosts. Results of preliminary experiments made with the fungus upon culture media indicate that Rhizoctonia grows vigorously on a neutral or acid medium but is greatly retarded on an alkaline medium.

Rhizoctonia, which is fairly cosmopolitan, seems to flourish especially well on all types of arid soil, tho it is capable of growth under almost any soil or climatic condition.

An exhaustive study of the fungus and its relation to its various hosts is being made under laboratory, greenhouse and field conditions. The behavior of the fungus in different types of soils and the relation of crop rotation and tillage methods to its development is also under investigation. Improved methods of combatting the diseases by the treatment of seed and soil are also being worked out. The losses in the bean, potato, tomato and other crops of the Northwest from this fungus, run into hundreds of thousands of dollars annually. Therefore, the work upon the project will be prosecuted actively.

Identification and Study of Miscellaneous Diseases and Fungi.

This work has been continued as in previous years, tho it has increased considerably, and inquiries from the following sources have been given attention:

1st. General disease inquiries from farmers, orchardists, or others interested in plant production.

2nd. Specimens submitted by county agriculturists and state horticultural inspectors.

3rd. Diseases coming within the observation of the pathologist and assistants.

Over 500 plant diseases have been examined during the year and not only reported upon in detail to the parties concerned, but records including specimens have been kept on file in the department. These diseases cover a wide range, practically all of our domestic plants being involved. The work is one of the most valuable contributions the Station makes to the agricultural interests of the state.

Fire Blight.

Work upon this project was started during the year in

question. Two phases of the work have been completed and published as follows:

(a) The establishment of the fact that leaf invasions by *Bacillus amylovorus* are of common occurrence in our territory marks the first advance on this project. The results have been published in Bulletin 125 of this Station, in "Better Fruit," of May and June, 1916, and in the Annual Report of the Washington State Horticultural Association for 1916.

(b) Fruit lesions of the apple. A study was made of a peculiar type of fruit attack due to the blight bacteria. A brief record of this will be found in "Some New Facts

Fig. III. Fire blight in apple leaves showing characteristic terminal and marginal invasions by Bacillus amylovorous. After Heald, Fig. I., Gen. Bul. No. 125, Wash. Exp. Sta.

Concerning Fire Blight" in Ann. Rept. Wash. State Hort. Assoc. for 1916, p. 32-33, and also in Better Fruit," for May, 1916, p. 21-22. The characteristic lesions are illustrated in the former publication,, p. 33.

A large number of plantings have been made in the pathologium for the continuation of the project, work upon which, however, at the present time is temporarily suspended on account of shortage of funds.

Wheat Smut.

The most notable results obtained in this division, and probably by the Station during the year, are the investigations upon the control of wheat smut *(Tilletia tritici)*. This disease is undoubtedly one of the most serious of the agricultural diseases of the Northwest, causing a loss in Eastern Washington, Northern Idaho and Northeastern Oregon of probably fifteen million dollars per year in the wheat crop. It has been found that infection of seed by smut arises from two sources: *First,* from smut spores adhering to the wheat grain and infecting at the time of sprouting. This method, of course, has been known for years and can be successfully combatted by the use of any adequate seed treatment found most convenient,—copper sulfate or formaldehyde (copper sulfate 1 lb., sodium chloride 1 lb., water 5 gal., treatment 10 minutes; or formaldehyde 40%, 1 lb., water 30 gal., treatment 30 minutes). The *second method* of infection, hitherto unknown, arises from smut spores which settle upon summer-fallow ground during the threshing season. These spores lie upon the summer fallow until tilled into the soil immediately following the first fall rains when seeding of wheat commences, thus smut spores in enormous quantities and wheat seed are planted in the soil simultaneously and under good growing conditions, infection occurring, of course, in spite of careful seed treatment.

It has been found that during the threshing season, smut spores settle upon the ground at the rate of several hundred thousand per square inch over the entire country. It has also been found that wheat seeded before threshing season commences (July or early August), thus preceding the smut shower, produces a practically smut-free crop if the seed has been properly treated. Further, it has been found that if seeding is deferred until later in the season (last of October or first of November), the smut spores scattered over the soil will have germinated and little infection of wheat occurs. The Station is, therefore, tentatively recommending either early or late seeding of fall wheat. Early seeding has an advantage of producing an abundance of fall pasture, thus

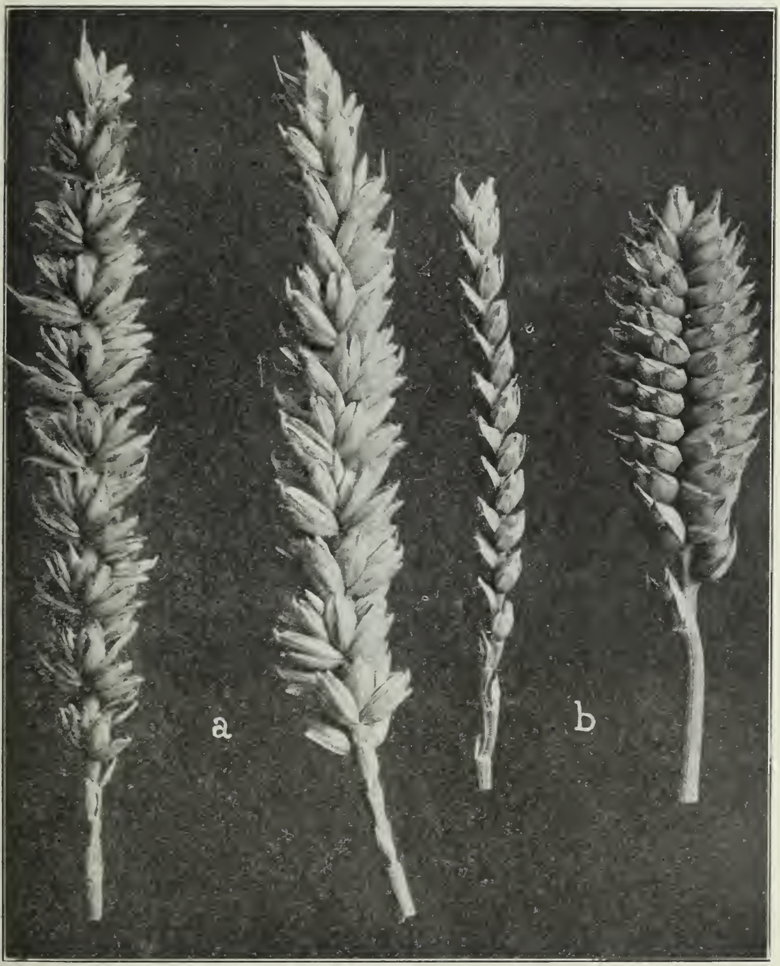

Fig. IV. (a) Smutted and normal heads of Winter Fife. (b) Smutted and normal heads of Hybrid 108. After Heald, Fig. III., Gen. Bul. 126, Wash. Exp. Sta.

increasing the summer and fall feed for live stock. Late seeding has the advantage of coming at a time when farmers are less crowded with other work and also obviates the necessity of carrying over for an entire year, the necessary seed. Some farmers, also, believe that late seeding gives slightly higher yields than very early seeding, however, the reverse has been the case in our tests upon the Station farm this year.

Fig. V. (a) Partially smutted berries of Red Russian. (b) Partially smutted berries of Hybrid 128. After Heald, Fig. V., Gen. Bul. 126, Wash. Exp. Sta.

An automatic sprinkler and fire extinguisher has also been devised and perfected by the Station, and its trial by a large number of threshing outfits in the Palouse country, has proven the apparatus to be an efficient precautionary device for the control of separator fires. Further investigations along the line of collection and removal of the dust from separators will be conducted during the coming season, while the investigations upon smut from a pathological standpoint will be prosecuted with renewed vigor.

Powdery Mildew of the Apple.

Work upon this project during the year has been confined largely to a study of spore dissemination.

Gooseberry Mildew.

Work has continued upon this project with reference to the control of the disease by the use of lime sulfur and a study has also been made of the method of spore dissemination.

Experiments are also being conducted upon the silver scurf of potatoes, current anthracnose, clover anthracnose, alfalfa mildew, alfalfa blight, and net necrosis of potatoes.

Physiology.

The Progressive Development of the Wheat Kernel.

This project is one conducted jointly by the Divisions of Botany and Chemistry, the botanical department doing the work of cytological and microchemical nature, and the chemistry division doing the work of a macro-chemical nature.

Certain lines of the work have been completed and the report of the same will be published shortly.

Thru the co-operation of the Department of Botany of the University of Chicago, the services of Dr. Sophia Eckerson were secured for the completion of the microchemical phase of this work, the results of which may be summarized as follows:

Inorganic materials are high in the young plant. The largest amount of potassium nitrate was found chiefly in the root and stem, just before formation of the spike. From that time on, it decreases gradually.

Free magnesium quickly falls to a minimum during formation of the aleurone.

Free phosphate rapidly rises to a maximum during development of the sporogenous tissue; after development of the sex cells it falls to a minimum.

Asparagine seems to be a very important nutritive substance for growth. It was found together with fructose in all young growing regions.

Pectic substances on the stigma are especially important in reducing the rate of water absorption by pollen grains.

From fertilization of the egg to the mature grain a stream of nutrient materials for the growing embryo comes to the endosperm from the leaves and glumes; fructose and glucose, asparagine, arginine, histidine, and leucine. Any excess sugar condenses at once into starch. The excess asparagine and

amino acids remain as such in the endosperm cells until desiccation of the grain begins.

The nitrogen compounds, aside from aleurone and protoplasm, in the endosperm just before ripening of the grain are: much asparagine, considerable arginine, histidine, and some leucine. No glutamine was found.

On desiccation of the grain protein appears in the storage cells; the amino-acids and most of the asparagine disappear. The protein has the physical characters of gluten.

Formation of the storage protein in wheat seems to be a condensation process, and it takes place on desiccation of the kernel.

In connection with the above, the morphology of the wheat has also been studied, especially from the standpoint of the detailed development of all floral structures. The manuscript for this work is ready for the printer and will shortly be published.

These two contributions will add very materially to our knowledge of the minute structure and physiology of the wheat plant.

Physiological Effect of Sprays.

Work has been conducted upon the physiological effect of sprays upon green plants with a view to determining the actual effect upon the production of fruit in these plants and the underlying cause of this influence. Work was conducted both under field and laboratory conditions, study being made of the effect upon transpiration, respiration, and photosynthesis of plants under controlled conditions.

Fruit By-products.

Work was commenced upon this project near the middle of the fiscal year in question. Dr. J. S. Caldwell, in charge of the work, visited a number of by-products plants and laboratories in Washington, D. C., New York state and other portions of the country, making a careful investigation of the operation, methods, costs, etc., of these plants, which was followed by a like study, covering the same aspects of the business, of some representative by-product plants in the Northwestern states. Special attention was given to the manufacture of fruit juices, ciders, jellies, vinegars, etc., and a large amount of data accumulated which is being used in assisting those interested in the by-products industry of the

state. A study has also been made of the utilization of low-grade and unmarketable fruit, utilization of apple pomace, pits, seeds and other by-products in the manufacture of oils, perfumes, soaps, fertilizers, etc., as conducted in the laboratories.

While the utilization of some of the above mentioned products is of minor importance as compared with the utilization of some of the lower grade fruits themselves, it must be pointed out that the whole business of the manufacture of fruits into salable staple products is one yielding a low margin of profit, and that it can be put upon a basis of assured and constant returns only when complete utilization of the potential value of every part of the material handled is accomplished.

A large amount of time has been spent in a study of the evaporation of apples as conducted elsewhere, especially in New York state. In conducting this investigation, information was obtained along the following lines:

1. Type of evaporators and evaporator equipment in use.

2. Costs of construction, equipment, maintenance and cost of production of evaporated apples.

3. The extent to which other fruits and vegetables are or can be handled with the equipment used for evaporating apples.

4. The degree of inter-relation and co-operation between evaporators, canners, cider, vinegar and jelly manufacturers.

5. The extent to which co-operative or community by-products plants have been found successful as compared with those owned by individuals.

6. Effects of various degrees and methods of drying on quality and stability of products.

7. Marketing methods and possibilities for further expansion.

The results of these investigations indicate that evaporation of apples as an industry has developed with very little scientific basis or aid. A great majority of the plants operate for only 2 or 3 months a year under normal conditions and none of them are operated in connection with canneries, vinegar factories, or other fruit by-products plants. In many cases the wastes of the evaporating plants are sold to such plants. Practically all evaporating plants are individually

owned, the co-operative or community plants apparently not being popular.

It was found also that there exists great variation in quality of products, there seemingly being no definite standard with reference to moisture content of evaporated fruit. The results of these investigations have been published as Bulletin No. 131 entitled, "The Evaporation of Apples." A summary of the contents of this bulletin will be found on another page of this report.

In addition to the data here published, work looking to the development of better methods for sterilizing and filtering fruit juice, as apple and loganberry juice, for use as beverages, is under way; methods for improving the quality of home-made apple vinegar have been investigated, and a study of the market conditions and possibilities for fruit products, both in the United States and abroad, is being made. There has been accumulated in the files of the department a large amount of information which at all times is fully available to those interested in the by-products industry. The Station has, thru conferences, meetings, lectures, etc., contributed materially toward the establishment of this industry upon a rational basis in this state.

Work along the lines of processing and handling of fruit and fruit by-products and biochemical studies of fruit composition is being continued.

DIVISION OF CHEMISTRY

In addition to a large amount of miscellaneous analytical work, this department does the analytical work for the State Department of Agriculture in the inspection of foods, feeds, oils, fertilizers, fungicides, insecticides, etc.

Function of Sulfur as Plant Food Material.

In previous studies the attempt has been made to measure the sulfur content of virgin and cultivated soils, as well as to study the sulfur contained in the crops removed from soils under controlled conditions. The progress of our work with restricted supplies of sulfur under greenhouse conditions points to the importance of sulfur in a very marked degree, and it is hoped that the work will eventually indicate the ratio of sulfur to other plant food materials necessary to bring about the best results.

Soils selected for a portion of the work were obtained in localities where definite information as to variety and number of crops removed, was obtainable. One of the interesting features in connection with the work is the great variability in the sulfur composition of different soils. In some instances as much sulfur is found in cultivated soils as in soils recently formed thru rock decomposition. On the whole, however, the recently formed soils are considerably richer in sulfur than those found as virgin or under cultivation. It is possible some of the results of this work will be published in bulletin form during the coming year.

Relation of Composition of Wheat to Soil Types.

The work during the past year upon this project had to do chiefly with the soil upon the different hill slopes, namely: north slope, south slope and top. Soil from the different positions with reference to the slope, was transferred to the green house and crops grown under controlled conditions and under field conditions were observed. The results are as yet inconclusive, however, this investigation ought soon to throw considerable light upon the requisite methods of tillage for the hilly prairies of Eastern Washington.

Influence of Cultivation on the Nitrogen Content of Wheat Seeded Different Distances Apart.

Previous observations have shown that wheat grown under irrigated conditions and receiving 20 inches of water, contained as much nitrogen as was found in wheat receiving lesser amounts of water. A continuation of this experiment this year gave similar results, thus indicating that water if properly applied, is a benefit rather than a detriment to high nitrogen composition.

Approximately 2000 nitrogen determinations of samples of different varieties of wheat grown under different conditions were made during the year. From the standpoint of the relation of cultivation to nitrogen content, the results are as yet inconclusive. As usual the nitrogen content of spring wheats grown at Pullman was found to be high. Of these wheats, the lowest percentage (2.41) was found in Red Chaff. The highest percentage of nitrogen (3.15) was found in Little Club. Among the winter wheats grown at Pullman,

Jones Winter Fife (2.11), had the lowest percentage with Turkey X Bluestem Hybrid (3.03) as highest. It was found that the highest average nitrogen content (2.82) occurred in wheat grown upon summer fallow, while the lowest average (1.62%) was from seed that was grown on ground used for production of wheat hay the year previous. Following summer fallow, the nitrogen content of wheat diminished in order after the following crops: potatoes, carrots, beets, beans and peas.

Co-operation with Association of Official Agricultural Chemists.

This is a line of work of the utmost importance to Experiment Station workers thruout the country, in that it brings into co-operative relationship all of the agricultural chemists of the country who are engaged in investigational work. The benefits of the experiments of other laboratories in solving detailed technical problems are thus soon made common knowledge. It is to be greatly regretted that the funds of the Experiment Station during the past year have not permitted the Washington Station to carry its share of the co-operation in this arrangement.

Analysis of Insecticides and Fungicides.

The work of analysis of insecticides and fungicides has been conducted as in previous years with a view to acquainting the farmer with the character and value of these products. In general it may be stated that marked improvement is noted in the quality of these materials sold in the state.

Preservation of Eggs.

Work has also been conducted on the preservation of eggs by improved methods in the use of water glass solution with a view to thus preserving eggs in such a way that they will be suitable for the making of meringues, icings, angel cake and other pastry products. The investigations thus far promise success in these lines.

Suspended Projects.

Two important projects, one on liming alfalfa and the other on the baking qualities of flour, had to be discontinued during the year on account of lack of financial support.

State Chemist Work.

Under the state law the chemist of the Experiment Station is state chemist, and as such, a separate report is rendered covering this type of work.

DRY LAND DIVISION

At the beginning of the fiscal year in question, a branch experiment station was established at Lind, Washington, upon a half section of land provided by Adams County, the equipment for the same being provided largely from donations made by certain public spirited gentlemen in Spokane and by the Chicago, Milwaukee, and St. Paul Railway. The maintenance of this station during the year was provided from

Fig. VI. The Station is making an effort to establish the cultivation of forage crops in the drier districts of the state. The above field of sweet clover was grown upon the Adams County Demonstration Farm at Cunningham. Photographed June 15, 1914. After McCall, Fig. IV., Gen. Bul. 128, Wash. Exp. Sta.

funds appropriated by the Experiment Station, and from an appropriation of $2500 from the Office of Cereal Investigations, U. S. Department of Agriculture.

Simultaneously with the starting of work on this station, a station was also established at Waterville upon 60 acres of land leased from the Waterville School Board on a 25-year lease. These two stations have been placed under one management, the superintendent residing at Lind.

The Lind Station is established upon a light volcanic ash soil, low in humus content and under a rainfall of approximately 10 inches, at an altitude of 1600 feet and has a high evaporation rate, the rainfall coming principally during the non-growing season. The winters are mild with little snow; the summers hot and dry. Wind movements are uniformly constant and often high in velocity.

The Station at Waterville is located upon a plateau in the bend of the Columbia River, at an altitude of 2600 feet, upon a heavy black soil and under a rainfall of 12 to 13 inches. Its climate is not extreme either in winter or summer, except that during winter there is a heavy snowfall which usually lies on to a depth of several feet for three or four months.

Upon these two sub-stations, experiments in dry land agriculture are being conducted at present under five projects:

First, cereal investigations, to determine those cereals best suited to the district, also rates, dates, and depths of seeding, methods of control of cereal diseases, together with breeding for cereal improvement.

Second, forage investigations, with a view to determining comparative merits of different forage crops and improvement of the same, also the use of silage.

Third, tillage investigations to determine proper time and manner of tilling soil in the preparation and handling of summer fallow under the extreme dry land conditions.

Fourth, permanent fertility investigations to determine plant food limitations and possible permanency, and to develop methods for maintenance of fertility by means of fertilizer trials, maintenance of organic matter, and rotations.

Fifth, tree investigations and distribution to determine those trees and shrubs most suitable for conditions in Central Washington with reference to their use as ornamentals, windbreaks and for economic purposes, also to grow and distribute such trees among the farmers.

Pure-bred stock for breeding purposes is also being made available thru the Station.

At the Waterville Station the intention is to lay especial emphasis upon forage crop investigations.

A number of weather observation stations are being established with a view to obtaining more specific data in

regard to the climate of the district in question. The work of these sub-stations is of course just getting started.

Of necessity, the establishment of stations of this type calls for a good deal of preliminary work, not of strictly investigational character. The farm at Lind had to be fenced, freed from weeds and put into a good state of tilth. It was, with the exception of a well, virtually unimproved.

During the year there has been constructed upon the Station Farm, a five-room foreman's cottage, a good sized barn, a machine shed and shop, and there has also been installed a pneumatic water system, and a septic tank; 1520 rods of hog-tight fencing have also been built.

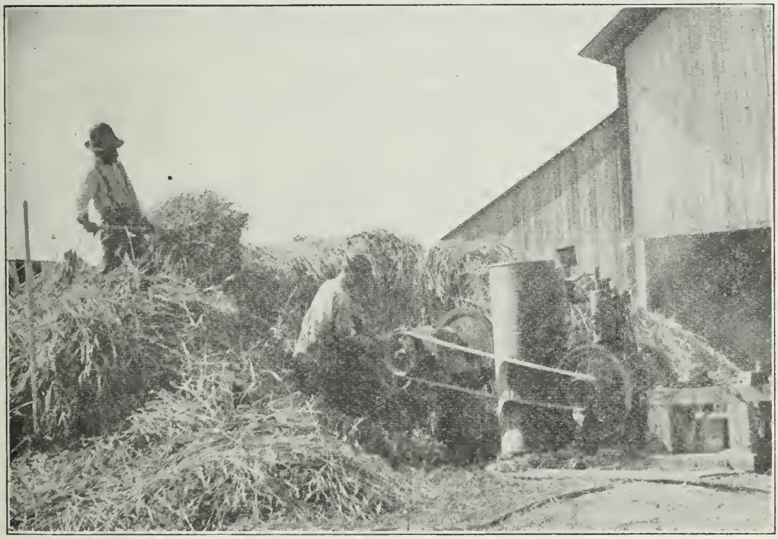

Fig. VII. Filling a pit silo in Grant County. Spring wheat is being used in this case for the silage. The procuring of succulent feed is one of the important agricultural problems of the drier districts. Utilization of wheat or rye for silage doubtless will afford one means of solving the problems. After McCall, Fig. VIII., Gen. Bul. 128, Wash. Exp. Sta.

It is planned during the coming year to build upon the Station a laboratory and office building and a residence for the superintendent, who at present is obliged to live in Lind, a distance of three miles from the Station.

At the Waterville Station a building for storage of machinery, seed and grain, and to serve as a work-shop has

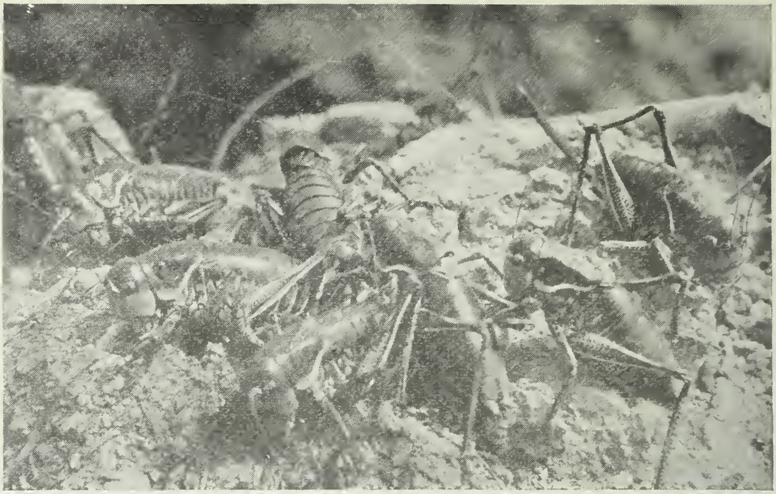

Fig. VIII. Coulee Crickets, (*Peranabrus scabricollis*). Natural size. This animal has caused serious damage in a small area of northern Grant County. After Melander, Fig. XXI., Gen. Bul. 137, Wash. Exp. Sta.

Fig. IX. Progressive growth of Coulee Cricket from egg to adult. Upper row female, lower row male. Almost natural size. After Melander, Fig. IX., Gen. Bul. No. 137, Wash. Exp. Sta.

been constructed. The land itself has been prepared for experimental purposes and fenced with a wire fence, part of which was donated by The American Steel and Wire Co.

This department has also conducted during the past year, as during the previous one, co-operative demonstrational work in the Horse Heaven country with a large number of farmers. It has had a man in charge of the work in this district who has given his entire time to such work. As a result, it has come intimately in contact with and assisted practically every farmer in the district. Marked improvement in the agriculture in this portion of the state has resulted from the Station's efforts along these lines and it is earnestly recommended that this work be continued; however, the work being of a demonstrational rather than of an investigational character, it has been recommended that the same be transferred to the Extension Department of the College.

Inasmuch as there is being published a separate annual report of this Station, further details of the work may be obtained by consulting this report.*

DIVISION OF ZOOLOGY AND ENTOMOLOGY

In addition to the work upon the four regular projects, the department has identified, for citizens of the state, hundreds of insects and other animal pests.

The Coulee Cricket.

The Coulee Cricket *(Peranabrus scabricollis)*. As far back as 1899 this Station received inquiries about the coulee cricket, an insect practically restricted to certain portions of the scab lands of the Big Bend country, in Eastern Douglas and Northern Grant Counties. During the serious outbreak of these migratory insects in 1902 and 1903, emanating from the Moses Coulee, the Station undertook a study of their control by means of a South African Mucor, which was reputed successful in checking grasshopper incursions. These tests showed the disease of no value against the crickets and in the meantime the invasions subsided naturally. Three years ago, a new band of crickets became a menace to the northwest of Wilson Creek, when the assistant entomologist gave some study to the situation. Again, last year a general outbreak called the entomologist to the scene, control methods being worked upon in co-operation with an expert from the

*Gen. Bul. 138, Wash. Exp. Sta.

State Department of Agriculture. This year, 1916, the numbers of the crickets greatly multiplied and they became a most serious problem to the wheat growers of Grant County.

Fig. X. Ditching to prevent the migration of the Coulee Crickets. The cricket can not fly, therefore, when once in the ditch, is unable to get out. After Melander, Fig. XXIV., Gen. Bul. No. 137, Wash. Exp. Sta.

The Station entomologists were fortunate in securing almost consecutive information in the life cycle by repeated visits to the infested area so that a running account, amply illustrated with photographs, has been prepared for issuance in

bulletin form.* As the coulee cricket is one of the most spectacular of our destructive insects, the story of its behavior and the methods adopted for its control should prove of interest to the general public.

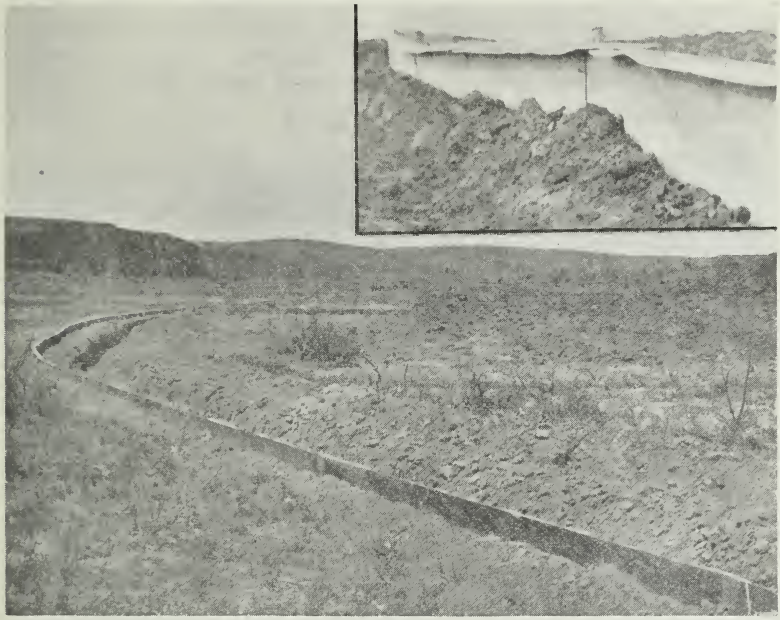

Fig. XI. Fence to prevent migrations of Coulee Crickets. Built with ship lap and capped with projecting sheet iron. Insert showing detail of construction. After Melander, Fig. XXVII., Gen. Bul. 137, Wash. Exp. Sta.

Strawberry Root Weevil *(Otiorrhynchus ovatus)*.

Owing to the threatened seriousness of the strawberry root weevil, a newcomer in the Kennewick region, whose insidious and destructive attacks are rendering acres of berry fields worthless, the Commissioners of Benton County appropriated the sum of five hundred dollars to be expended by the Experiment Station for a study of the pest. Two entomologists went to the infested district and devised a series of experiments. As the species works in subterranean fashion during the spring months, the line of attack was

*Gen. Bul. 137, Wash. Exp. Sta.

based on soil fumigation. Most of the materials used, such as crude carbolic acid, carco, carbolineum, kreso, borax, iron sulfate, soaps, carbon dioxide, sulfur dioxide and chlorine gases, lime sulphur, dormant soluble oil, turpentine, chloroform, kerosene, and gasoline, had no effect on the insect whatever. Cyanogen gas, generated either from an aqueous solution of sodium cyanide poured into the soil or by burying the cyanide powder directly, killed some of the insects but simultaneously destroyed the plants. The only material

Fig. XII. The worst strawberry pest of the country is the root weevil. The above illustration indicates the effect of the weevil upon the plant, the smaller one having been affected, the larger a normal plant. Photographed by Melander, from a Benton County field.

discovered that had promise of practical value was carbon disulphide, and this was practicable only when applied under cover, as under oilcloth or canvas. However, in view of the unusual value of the Kennewick strawberry fields the cost of weevil treatment with carbon disulphide under cover is neither prohibitive nor discouraging. An outline of the method of application has been issued in a press bulletin, and the treatment has already been carried on by several

growers on extended fields. The details of the study will be available for publication shortly and will make a distinct contribution to the little-known subject of soil disinfection.

Progressive Immunity of Insects.

In continuation of the work on the "Immunity to Sprays" project, the tests of the several preceding years were repeated early this spring at Clarkston, Walla Walla and North Yakima. As an interesting commentary on this

Fig. XIII. View of a Benton County strawberry field showing spots (in the foreground) where vines have been destroyed by the root weevil. Photographed by Melander.

project, at Wenatchee, where the scales have repeatedly manifested the greatest susceptibility to winter sprays, not enough living scales could be found in any single orchard to warrant carrying out the spraying tests. This mortality doubtless came from the record winter conditions. Possibly for the same reason the scales sprayed at Clarkston behaved in an anomalous manner, a large percentage succumbing readily to lime-sulfur in contradiction to their behavior of previous

years. On the other hand the scales at Clarkston were remarkably resistant to standard emulsified oils. The curves and tabulations of this extended investigation will be correlated and edited for submission as a Station bulletin.

Fig. XIV. Strawberry Root Weevil (*Otiorrhynchus ovatus*). Stages of development from larva to adult, magnified four times.

Fig. XV. Strawberry field, Benton County. Illustrating methods of combating strawberry root weevil. Canvas strips covering infected portion of rows. Under these strips is placed a small amount of carbon disulfid. Photographed by Melander.

The Physiological Effects of Endoparasitism in Aphids.

These studies were continued in general much the same as heretofore in an endeavor to clear up certain points of considerable importance toward the solution of the problem and to verify certain seemingly apparent facts previously in-

dicated. The more important phases of the problem which were studied during the year were as follows:

1. It has recently been established that there are two species of Aphis commonly found infesting the cabbage and turnip and certain other Cruciferae. Investigations were made to determine whether both species were alike preyed upon by the various parasites previously studied, and there was found no apparent difference between the two species as hosts in so far as the parasites are concerned.

2. The biology of the two species of aphids were studied inasmuch as many of the data are of the utmost significance with regard to their bearing upon the problem.

3. The biology of the several parasites were also studied, both independent of the fact of their manner of life, and in relation to their hosts and to one another.

4. Polyembryony, which is characteristic of certain species of parasites, was found not to exist in any of the species of parasites studied.

5. Parthenogenesis was definitely ascertained to be possible under certain conditions, the resulting offspring being invariably males.

6. The Cabbage aphis *(Aphis brassicae)* and the turnip louse *(Aphis pseudobrassicae)* are both attacked by a fungous parasite which destroys many of them. It was found that this fungus is especially destructive in the late autumn during cool, damp weather, which seems necessary for its proper development.

7. It was definitely determined that one method of dissemination of the endoparasites was thru the agency of the winged host forms. The parasites oviposit in the winged form, which migrate to other plants or to other fields and in that manner distribute the parasites.

8. An important discovery was made concerning the inter-relation of the endoparasites themselves. It has been supposed, for a number of years, that perhaps one of the parasites *(Pachyneuron micans)* was a hyperparasite upon one of the other parasites. It was definitely determined during the past year that such is actually the case. Females of *Pachyneuron micans* were seen ovipositing in aphid hosts which were already dead from previous parasitism, and from these hosts adult *P. micans* subsequently emerged. *Asrophes rufipes* is also undoubtedly a hyperparasite since it, like *Pachy-*

neuron micans, always emerges from a given lot of hosts much later than the other parasites.

9. One phase of the problem having especial economic bearing—as to whether parasitized aphids bear further offspring—was given considerable attention and it was found that reproduction does not cease immediately after the host has been oviposited in, but that it may continue for some days, several young being produced. This is an important point, for if the bearing of young is materially lessened thru parasitism, even before the parent's death, it increases manyfold the effectiveness of that parasitism.

DIVISION OF HORTICULTURE

Mendel's Law in Relation to Raspberry and Blackberry Hybrids.

Owing to the nature of the project, tangible results are procured slowly. Work during the year has been conducted with the following varieties of Rubus:

occidentalis
neglectus
strigosus
Idaesus
nigrobaccus-sativus
nigrobaccus-villosus
argutus
laciniatus

From these have been procured something like 2000 seedlings of F_2 hybrids. Thus far difficulty has been experienced in segregating the unit characters of the organisms. On this account, and on account of the fact that the plants mature slowly, results are not forthcoming as readily as was hoped.

Winter Desiccation of Fruit Trees.

The experience of the orchardists in the irrigated sections of the Northwest is that apple rosette in all forms disappears after the orchard has been planted to alfalfa or clover for two or three years. A survey of the Wenatchee district confirms this and the same is true in the irrigated sections of Idaho. Tests were made to ascertain whether the alkali content of the soil was appreciably modified by the growing of these crops, as compared with clean tilled land. Samples were taken from fifty orchards, part of which were

given clean tillage and part planted to alfalfa or red clover for three years or longer. The results obtained in the analysis of these samples indicate that the alkali content of the soil to a depth of two feet was slightly reduced in the cover-cropped orchards. This reduction was very slight, being only .002 of one per cent, however, and it does not seem possible for it to have any appreciable influence on the plant growth.

Tests were made of the humus and volatile content of the same soil samples. The humus and volatile content of the soil was increased only .03 of one per cent. This does not seem to be enough to have any possible modifying influence over the well-being of orchard trees.

Winter injury occurs in orchards that have rosette but it seems to have no direct relation to rosette. The winter injury of the trunk and larger limbs does not as a rule occure in rosetted orchards but is most frequent in those free from that trouble.

In the fiscal year of 1916-17 it is purposed to go still further into soil analysis and examination of the root system of the affected trees.

Shade and Ornamental Trees and Shrubs.

Two projects, the work of which consists largely in making observations and keeping of records (a) shade and ornamental trees, (b) ornamental shrubs and vines, suitable for the state, have been in progress for about eight years. Observations have been taken upon upwards of 140 kinds of plants, with a result that some definite information has been obtained with reference to those most suitable for the state. The results of these observations will be published during the coming year.

Orchard Pollination.

The work upon orchard pollination this year practically came to naught on account of the cold, windy weather during the blossoming time.

Soil Moisture and Keeping Quality of Apples.

Work upon the relation of soil moisture to the keeping quality of apples was conducted with Jonathan and Rome Beauty, and chiefly with fruit grown in the Wenatchee Valley. There was very little difference noted in the date of ripen-

ing upon plots whirh received 12, 9 and 6.6% of water, respectively. It has been noted that the large sized fruits of any variety ripened first, regardless of the moisture condition. The project is also being conducted from the stand point of the effect of moisture on the keeping quality.

Orchard Cover Crops.

In the study of orchard cover crops it is found that the growing of peas and vetch as cover crops has produced the best physical condition of the soil so far as effect of growth of trees is concerned. There seems to be little difference between a cover crop of oats, wheat, rye, vetch or peas.

Renovation of Prune Orchards.

In the experiments on the renovation of orchards in Clarke County, it has been found that great improvement in the production and quality of prunes can be secured by the use of lime and nitrogen fertilizers. The use of barnyard manure has in most cases not given satisfactory results, probably largely due to methods of application. Work upon the project had to be dropped on account of lack of funds.

Vegetable Testing.

In experiments in the variety testing of garden vegetables, the work has been concentrated chiefly upon potatoes, some eighty varieties being under test.

Of the early varieties, Earliest of All, Early Sunrise, and Early Rose, gave the highest yields and in general were the most satisfactory. In the list of main crop varieties, Producer, Snow, American Wonder and Carmen No. 2, were the best yielding varieties and were the most satisfactory.

It has been found that the character of storage of seed has much to do with the stand of plants produced.

Frost Injury.

This project has for its purpose the study of methods of handling plants which have been more or less damaged by frost. The project is a new one, having been just started during the year.

DIVISION OF IRRIGATION ENGINEERING

Aside from a limited amount of investigations upon the cost of irrigation pumping and the publication of the results

in Popular Bulletin No. 104, no work has been carried on in this department during the year. The Head of the department has given considerable assistance to farmers by way of conference and correspondence. However, there is needed funds for further investigational work in the field of irrigation engineering, and it is hoped that the Station may be able to take up such work in the near future.

DIVISION OF VETERINARY SCIENCE

This division has in charge, three projects: goiter and associated conditions, red water, and pernicious anemia. No work has been done, however, upon the last two mentioned

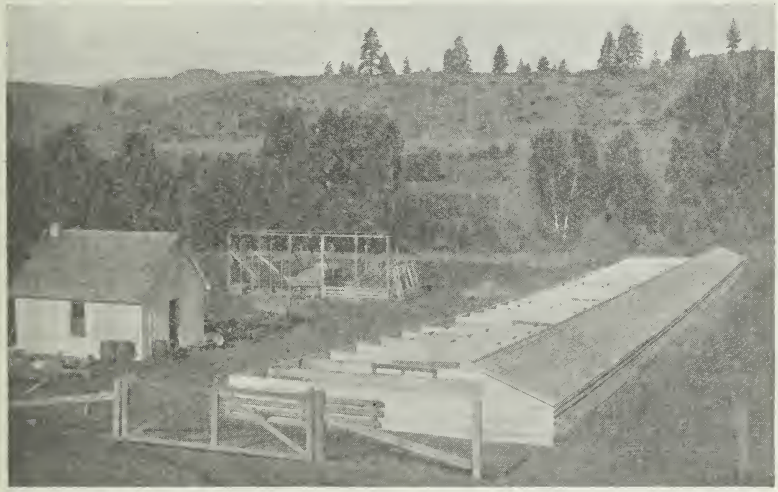

Fig. XVI. View of experimental pens used in study of animal diseases at the temporary station near Winthrop. Cascade Mountains in background. The Methow River is in the fringe of trees beyond the pens. Photographed by Kalkus.

projects during the year on account of lack of material. Upon the goiter project, however, a considerable amount of work has been done. A temporary station for the study of this disease has been established in the Methow Valley between Twisp and Winthrop, where approximately 100 head of swine, sheep and goats are now quartered under controlled conditions in this investigation.

A large amount of data has been obtained during the year, however, none of it is sufficiently conclusive as yet to enable a determination of the cause of the disease. Some of the results are more or less conflicting in character.

Besides the experimental work which has been carried on it was possible during the months of April and May of this year for the Station Veterinarian to make a number of interesting observations on animals in the Methow Valley. Each year there is quite a large percentage of mortality among calves here and because "big neck" or goiter is so prevalent, the loss has been attributed largely to this condition. Some ranchers have lost over 50 per cent of their calves, most of which were born prematurely, and all had "big neck." In the majority of cases, the calves were aborted at about the fifth or sixth month of pregnancy. Most of the animals were ranch cattle.

The Station veterinarian had opportunity to autopsy a number of these dead calves, many of which had a marked enlargement of the thyroid glands. Samples of blood were secured from cows which had aborted goiter calves for the purpose of determining the relation of the goiter and abortion. It has been found that a number of calves in this district have died of pneumonia, and since it is found that calves which are born in summer are stronger than those which are dropped in the early spring, it is the opinion of the Station veterinarian that a considerable amount of the trouble with young live stock is due to exposure to inclement weather. Observations made upon a herd of one hundred ewes on Siwash Creek in the Okanogan Valley, indicate that the eating of snow by these animals may have had something to do with the prevalence of "big neck" among them, since "big neck" had not been known in this vicinity before, and last year more than 50 per cent of 160 lambs produced, had the ailment. The autopsy of a large number of hairless pigs indicates that goiter is not necessarily associated with hairlessness.

It is the plan to continue this work as during the past year, also adding cattle to the stock already under investigation, especially for the study of the treatment of cows during the period of gestation.

CO-OPERATIVE WORK

The co-operative work of the Experiment Station with other institutions, organizations and various individuals interested in agricultural development has increased many-fold during the past three or four years.

With the State Department of Agriculture, the Station has co-operated in many lines to mutual advantage. Horticultural Inspectors from the State Department have rendered valuable assistance to the Station men in conducting field investigations. In the procuring of material for investigation upon animal diseases, assistance also has been rendered by the Livestock Division of the State Department, while in the enforcement of quarantine and control of diseases, both plant and animal, the Station has rendered technical assistance in many ways to the State Department. The analytical work in connection with the inspection of feeds, foods, fertilizers, insecticides and fungicides is done in the chemistry department of the Station. The Horticultural Inspectors of the State Department also spent a week at the Station in conference with the various Station experts with a view to improving the service of both Departments. In general, the best of feeling and heartiest spirit of co-operation exists between these two great Departments interested in the physical and economic development of the state.

Co-operation with the U. S. Department of Agriculture with the purpose of determining the effect of varying conditions of climate and soil upon the chemical condition of wheat and its yield has been continued. The Bureau of Plant Industry not only has continued its co-operation upon the investigation of wheat smut, but has also contributed $2500 per year for co-operative work in dry land investigations. Arrangements have also been completed for an increase to the amount of $700 per year from the U. S. Department of Agriculture in the smut work. This fund becomes available with the beginning of the fiscal year 1916-17. The Station is also co-operating with the Office of Foreign Seed and Plant Introduction of the U. S. Department in the introduction of new and improved seed, and with the Weather Bureau in the collection of meteorological data.

The Department of Botany of the University of Chicago has co-operated in the investigations upon the development of the wheat grain.

The Idaho Experiment Station has co-operated, and is co-operating, with the Station upon fruit by-products, the relation of soil types to the production and quality of wheat, apple rosette, and also in the publication and distribution of bulletins.

In the handling of its field work thru the state, the Station has also had the co-operation of some five hundred farmers.

Within the State College itself especial mention must be made of the valuable co-operative work with the Department of Forestry in the distribution of trees to the dry districts; the Department of Botany in the analysis of seeds, the bacteriological examination of milk and other dairy products, the identification of weeds, and also assistance in investigational work by Dr. G. H. Jensen in the development of wheat and fruit by-products; Dr. Hannah Aase in the work in plant breeding, and Mr. E. M. Hall on the physiological effect of sprays. In the Department of Animal Husbandry, Mr. E. B. Krantz has assisted in feeding investigations and Mr. C. E. Howell in connection with the range sheep investigations. The Departments of Architecture and Farm Mechanics have co-operated with the Station in the preparation of building plans for the Adams Branch Station.

In addition to the above mentioned co-operative work the Station has had the co-operation in the shape of financial assistance, from a number of individuals and corporations, definite mention of which is made in another portion of this report.

DISSEMINATION OF INFORMATION

The investigational work mentioned in the previous pages, while representing the more important phase of the Experiment Station activities, still is ineffective unless the information obtained is properly disseminated. The Station endeavors to effectively place the information acquired in its investigational work before the public by means of three series of bulletins; a technical series, which is sent primarily to scientific, technical and agricultural journals; a popular series, which is sent to farmers, agricultural journals and newspapers, and a newspaper series, which is sent to the agricultural journals of the country and to all newspapers of the Northwest,—some 750 in all.

There has been published by the Station during the year, ten technical, eleven popular and thirty-one newspaper bulletins, aggregating 641 pages.

General (Technical) Bulletins.

No. 123. Time and Method of Tillage on the Yield and Comparative Cost of Production of Wheat in the Palouse Region of Eastern Washington, by C. C. Thom and H. F. Holtz. This bulletin contains the results of one year's tests of crops grown under different methods of tillage and rotation. The results set forth are, of course, tentative, yet of value as indicating the net returns to be obtained from Palouse land under different farm practice. They would indicate that corn and wheat alternating with fall plowing each year is the most profitable of the eleven cropping systems tested, while peas and wheat alternating upon fall plowing rank second, both outranking wheat and summer fallow from five to ten dollars per acre in net returns.

No. 124. Bud Weevils and Other Bud-eating Insects of Washington, by M. A. Yothers. The bulletin is a progress report upon several years' work with bud weevils and other beetles native to the Columbia River Valley. These weevils normally live in the sage brush, but when land is cleared they infest the orchards, doing considerable damage for a number of years after the land has been in cultivation. Fourteen weevils and five other bettles were studied, both in their native habitat and in the insectary at the Station. A detailed discussion is given of the extent of injury and the distribution of the various species. Tabulated accounts of their behavior towards various foods is given, together with methods of control. The latter consists chiefly of protecting the trees by paper cones, thus preventing the animals from traveling up the tree trunk from the ground where they normally live. Cone protectors should be applied to the trees at the time of planting, as the beetles attack them immediately after. When upon the trees they can be shaken into an inverted umbrella and easily destroyed. The life history was worked out for some species and detailed information recorded with reference to dates, habits, food, etc. The bulletin is illustrated and a bibliography is included.

No. 125. Preliminary Note on Leaf Invasions by Bacillus Amylovorus, by F. D. Heald. During a blight epidemic ob-

servations were made in North Yakima, Spokane, Walla Walla, Kennewick and Prosser. It was found that the leaf infections by *Bacillus amylovorus* start at the margin, the infection doubtless taking place thru water pores, and travel thru veins and mid ribs of the leaf, finally thru the leaf petiole and into the twig. All stages of invasions were found from slight marginal infections to lesions which have advanced to the entire leaf blade and down the petiole. These leaf invasions were numerous and apparently are responsible for much loss from this disease. The bulletin is illustrated with photographs of typical leaf lesions.

No. 126. Bunt or Stinking Smut of Wheat, by F. D. Heald and H. M. Woolman. An illustrated bulletin of 24 pages with an introduction setting forth the prevalence and amount of loss caused by stinking smut. The life history of the smut is reviewed briefly, and a discussion is given of the variation in the partially smutted plants, heads and berries. The relation of smut to soil infection is discussed, it being pointed out that the scattering of smut spores at threshing time is largely responsible for the wheat infection the following year. Spore traps variously distributed indicate that upwards of half a million of spores may settle on each square inch of surface of the country generally during the threshing season. Attention is called to the relation of the time of seeding to the smut shower and the possibility of avoiding it by early or late seeding. The tests for crop rotation and the careful treatment of grain are pointed out as important features in controlling smut.

No. 127. The Twenty-Fifth Annual Report, by the Director. This bulletin discusses the work of the Station for the fiscal year ending June 30th, 1915, summarizes the needs of the Station and gives a review of the publications.

No. 128. Forage Crops in Central Washington, by M. A. McCall. The bulletin records the results of a year's testing upon corn, sorghums, alfalfa, sweet clover, field peas, rye and wheat, pointing out the relative values of these crops in the drier districts of Central Washington. "Considered from all angles, winter rye and wheat are as yet the best forage crops for Washington dry farmers." Results of the use of peas for "hogging-off," and rye for silage and pasture are given, as are also suggestions for rate and date of seed-

ing the different forage crops of the dry districts of Central Washington.

No. 129. Oats in Washington, by E. G. Schafer and E. F. Gaines. This bulletin gives a description of sixteen varieties of oats, which are more or less grown in the State of Washington, together with results of tests upon these and additional varieties upon the Experiment Station farm for the two years previous. These tests, while tentative, rank the varieties as follows: Abundance, Banner, Sparrowbill, Swedish Select, Sixty Day, Danish, Potato, Grey the average yield of Abundance being 114.9 bu. and Grey 89.1 bu. There is appended a brief statement with reference to the handling of loose smut in oats.

No. 130. The Dipterous Family Scatopsidae, by A. L. Melander. A 22-page, illustrated bulletin giving a taxonomic account of the Scatopsidae, a family of flies which spend their early life as scavengers in various kinds of decomposing organic matter.

No. 131. Evaporation of Apples, by J. S. Caldwell. The bulletin is a 112-page publication with numerous illustrations of plans and specifications for the construction of fruit evaporators. A general discussion is given of the present status of the apple industry of the state with an account of the extent of loss as a result of failure to utilize by-products and low-grade fruit. The conditions determining the type of by-products plant needed is discussed and cost data are given with reference to the possibilities of fruit evaporation in the Northwest. The market and marketing of evaporated fruit is discussed, as is also a review of the literature with reference to evaporation. Details, plans, cost data, etc., for the construction of the various types of fruit evaporators are set forth in considerable detail, as is also the relative merits of the different types of machinery and apparatus for running an evaporating plant. Information is given with reference to the relation of temperature and humidity to drying, controlling the moisture content of the product, grading and packing and the relative merits of the different varieties of apples for evaporating purposes.

No. 132. Isolation and Cultivation of Bacterium Tuberculosis on a Synthetic Culture Medium, by C. A. Magoon. This is a ten-page bulletin, reporting progress of work upon

the perfection of artificial, fat-free media and methods of isolation. The bulletin is technical in character, yet possibilities of practical application as a result of the work are great. "The practical value of this synthetic medium as a means of isolating the organism from tuberculosis is yet to be determined. As has been emphasized by other investigators, the value of synthetic media in the study of the metabolism of the organism, and especially in the preparation of tuberculins free from heterogeneous albuminoids, is very great. Preliminary examination of our rapidly growing cultures has shown them to possess marked antigenic properties, and their use in serological work shows much promise. Investigation as to their value in serum diagnoses are being pursued and will be the subject of a later paper." A bibliography is included.

Popular Bulletins.

No. 92. Feeding Dairy Cows in Washington, by A. B. Nystrom. This is a bulletin of 24 pages discussing the principles of feed selection for dairy cows, defining balanced ration, nutritive ratio and explaining composition of foods necessary in feeding the dairy herd. A detailed discussion is given of the different types of dry roughage, succulents and concentrates. Directions are given for making up an ideal ration, as well as general directions for feeding. Tabular statements of foods according to their nutritive value, are set forth, as are various combinations possible under Washington conditions. The bulletin also includes a table of the digestible nutrients and fertilizing constituents of the various types of feed.

No. 93. Rural Sanitation, by C. A. Magoon. This is a 60-page bulletin setting forth the principles of sanitation as applied to rural districts and the necessary means of improving sanitary conditions in the country. A brief discussion of the relation of bacteria to sanitation is given, followed by an account of the care of perishable foods, the disposal of kitchen wastes, the sources of pollution of drinking water and methods of treatment for the same. Sewage disposal under rural conditions is discussed, special emphasis is laid upon the handling of milk and the dairy industry generally, with a discussion of the diseases ordinarily spread by way of the dairy and dairy products. The bulletin is illustrated.

No. 94. Contagious Abortion in Cows, by J. W. Kalkus. This is a brief bulletin dealing with the nature and occurrence of contagious abortion. The cause and natural methods of infection of the disease, together with symptoms and methods of diagnosis are briefly explained. Methods of prevention and treatment are set forth in more or less detail, also directions for the disposal of aborting cows.

No. 95. The Dairy Barn and Milk House, How to Construct Them, by R. E. Hundertmark and A. B. Nystrom. A 40-page bulletin illustrated with plans and specifications of buildings and equipment, also bill of materials and costs. The bulletin points out the relation of good buildings and equipment to the progress and profits of the dairy industry. The different types of dairy barns and their location are discussed in considerable detail. Definite and detailed directions are given for the construction of both barn and milk house from foundation up.

No. 96. Butter Making on the Farm, by A. B. Nystrom and R. E. Hundertmark. This bulletin points out why farm butter is so often unsalable and gives detailed directions for the production of wholesome butter under sanitary conditions in the farm home. Methods of handling cream, churning, types of churns, washing and salting the butter and preparing the same for the market are described. The bulletin contains 24 pages and is illustrated.

No. 97. Dairy Herd Records, Their Value and How to Keep Them, by A. B. Nystrom and R. E. Hundertmark. The purpose of this bulletin is to enable the farmer to identify his good and poor cows. The value of the dairy herd record is pointed out, both from the standpoint of feeding, production and in the selling of stock. Directions are given for keeping records in detail, the bulletin being illustrated with record blanks and photographs of apparatus.

No. 98. Hot Bed Construction, by C. B. Sprague. An illustrated bulletin giving detailed directions and costs for the construction of hot beds and cold frames. The kind of material is described as is also the construction of the pit, preparation and care of manure, ventilation, planting, watering, etc., supplemented with the results of experiments conducted in the Station upon the use of hot beds.

No. 99. Ground Squirrel Control, by W. T. Shaw. The bulletin is a popularized statement of some of the investiga-

tions conducted for the past six years at the Station upon the life history and control of the Columbian Ground Squirrel *(Citellus columbianus columbianus)*. A brief account of the life history and habits of the squirrel is given, together with sketches illustrating their dens and runways. Methods of control are discussed under the heads of carbon disulfide, trapping and poison, detailed directions being given for the use of each method. The bulletin is illustrated with colored plates.

No. 100. The Control of Fruit Pests and Diseases, by A. L. Melander and F. D. Heald. A bulletin of 60 pages, discussing in considerable detail the characteristic appearance. effects of disease and methods of combating all of our more common insect pests and diseases of orchard fruits and berries. The bulletin was designed to supersede the spray calendar annually published by the Station, but to give more detailed and explicit directions than was possible in the calendar. In addition to describing 48 pests and approximately 60 diseases, the bulletin gives formulae and definite directions for the preparation of all the more common insecticides and fungicides.

No. 101. Controlling the Coulee Cricket, by A. L. Melander. This is a brief statement of methods of control for the Coulee Cricket, which has caused so much difficulty in Northern Grant County the past two years. The following methods of control are described in detail: spraying with kerosene emulsion, burning with a blast torch, burning in scattered straw, poisoning with arsenic, fencing the edge of threatened ranches, and ditching or trenching.

No. 102. Some Possibilities for the Utilization of Low-Grade and Surplus Fruit, by J. S. Caldwell. A brief popular resumé of General Bulletin No. 131, elsewhere noted in this report.

Newspaper Bulletins.

No.	
155	Treatment for Grasshoppers
156	Destroying Wasps
157	Weed Legislation
158	Sunflower: An Important Agricultural Crop
159	Purifying the Drinking Water
160	Bunt or Stinking Smut of Wheat
161	Wasps and Yellow-Jackets

162 Dairy Barn Construction
163 Apple Anthracnose or Black Spot Canker
164 Whitewash, a Paint Substitute
165 Mushroom Growing
166 Selection of Seed Corn
167 Hulless Oats
168 Inoculation for Legumes
169 Winter Injury of Fruit Trees
170 Char-pitting Stumps
171 The Kind of Spray Nozzle to Use
172 Squirrel Extermination
173 Field Peas
174 Have Your Seed Tested
175 Destroying Pocket Gophers
176 Soil Inoculation for Legumes
177 Eradication of Morning Glory
178 Ridding Horses, Cattle and Hogs of Lice
179 A Preventive and Cure for Worms in Hogs
180 Grasshopper Treatments
181 The Straw-Spreader on the Combine
182 The Strawberry Root Weevil
183 Fire Protection for Threshing Machines
184 When to Cut Hay
185 The Prospects for Wormy Apples

NEEDS OF THE EXPERIMENT STATION

One of the great problems in the evolution of a commonwealth such as the State of Washington, is the development of its physical resources. The state is exceedingly varied in character and has almost unlimited possibilities in the field of agricultural development, however, this variation in its physical characteristics greatly increases the complexity of the agricultural problem as a whole and makes necessary a greatly increased amount of scientific investigation in order to allow any reasonable and profitable progress in actual farm operation. The Experiment Station is daily in receipt of requests for information which it is unable to give, owing to the restricted amount of investigation which has been done upon the agricultural problems of the state. Without a constantly increasing fund of knowledge concerning these problems, our actual agricultural operations are certain to become more or less superficial and unprofitable, that, too, in

the not very distant future. Once this point in agricultural development is reached, the tide of emigration will set in from this to other agricultural districts more favored in public support than the State of Washington, and years will be required to restore confidence in the agricultural possibilities of the state.

From the standpoint of collegiate teaching, there is also need for an enormous amount of investigation. The instructors in the Department of Agriculture are, in many cases, utterly at a loss to determine what to teach their students with reference to the agriculture of Washington. The available text books are all based upon Eastern and Middle West conditions, and of course have little application to Northwest agriculture, nor are the same instructors able to write new texts, for their fund of information in regard to agricultural methods for this state is too inadequate. A quotation from a letter recently received from the head of the Division of Farm Crops in the Department of Agriculture will emphasize this point:

''The Department of Agriculture must obtain more information concerning systems of cropping and methods of handling farm crops in the Northwest, if the increasing number of students who graduate in Agriculture are to receive adequate instruction. * * * If we maintain efficiency in our collegiate work it will be necessary to offer the students instruction pertaining to cropping systems * * *. The cropping systems worked out in the Eastern states by the Experiment Stations cannot be substituted here because of the different climatic conditions. An illustration from the text which we are using in our course in Field Crops will emphasize this fact. The author outlines systems of crop rotation which are suitable for the New England states, for the North Atlantic states, for the Southeastern states and for the Central states, but says, 'In the Pacific states the systems of farming are yet too new for any general series of rotations to have been adopted.' * * *

''During the past few weeks the question came up as to how early fall wheat can be seeded on summer-fallow land, without decreasing the wheat yield. It was especially desirable to know this, as it has just been demonstrated that very early or very late seeded wheat would smut less badly than wheat seeded at the usual time, yet it was impossible to furnish definite information concerning this point * * *.

"I do not need to present argument to show you that Farm Crops is new as a subject of collegiate instruction and that less can be adopted from the work of other states than for many of the other courses given in the college * * *.

"The majority of the students taking agriculture are not well-to-do. They will not be able to own farms in the better developed sections of the state, or if they do the farms will necessarily be small and diversification will have to be practiced. Many, however, will have to seek lands in a new district brot under irrigation, the districts of light rainfall, or the logged-off lands. Even less is known concerning the proper systems of cropping in these localities than in the older settled districts of the state.

"The instructional side of the department looks to the Experiment Station for more information concerning these problems. Many of them can only be worked out by a series of experiments planned to be continued during a number of years and conducted in various parts of the state. * * *."

These are a few samples of the numerous demands which are made upon the Station for information, but which information the Station is unable to give because of its limited financial support.

There is urgently needed in this state at the present time, a great deal of investigation upon problems connected with irrigation agriculture. There are in the State of Washington at present, over 450,000 acres of irrigated land, mostly located in the central part of the state, tho there is scarcely a county in Eastern Washington that does not contain more or less irrigated land. A conservative estimate as to the value of these lands is above $70,000,000. While these areas and values are large, there is little doubt that they could be doubled or trebled within the next decade if adequate assistance is given in handling some of the technical problems connected with irrigation agriculture. It is, of course, out of the question for the Main Station at Pullman or either of the sub-stations at Lind or Waterville to adequately cope with irrigated problems. Such work must be done in irrigated districts, and it is strongly recommended that the state provide adequate funds for the establishment of a sub-station in irrigation agriculture in some one of the irrigated districts of the state. Such a station would require upon its staff a horticulturist, a plant pathologist, an entomologist and a soils specialist. It would require not less than $15,000 per

year for maintenance. Unless provision is made for such a sub-station there is certain to result enormous losses to the irrigation districts in the not very distant future.

Another problem of great consequence confronting the state today is that of land clearing. Washington contains within its borders upwards of 7,000,000 acres of logged-off lands. Much of this is good agricultural land. It should be developed and there are needed investigations along the line of more economical methods of land clearing for the purpose of aiding in this problem. These investigations do not call for large expenditures (in fact $9000 would probably suffice) and would, from their nature, be more or less temporary in character, their value, however, would be enormous, for the settlement of every acre of logged-off land in this state increases the assessed valuation from less than $2.00 per acre to $50 or $100 per acre.

In a district as remote from the centers of population as is the State of Washington, marketing of farm produce becomes especially difficult. It is, therefore, necessary that considerable investigation be carried on in this field of agriculture, for when the crop is produced, the battle is only half won for the farmer. It next remains for him to realize a profit from his labor and investment.

There exists in Southwestern Washington a new and flourishing industry—cranberry growing. Not only in Southwestern Washington, but in almost every country west of the Cascades, there are areas suitable for cranberry culture. This industry is an intensive type of agriculture, yielding large returns on small areas, yet the industry is attended with certain technical difficulties which call for scientific investigation if the cranberry business is to be adequately developed. It is, therefore, strongly urged that appropriations be made for the handling of this problem.

In connection with all of the above mentioned lines of work there is needed more information with reference to Washington soils. Detailed soil surveys and field tests of soils in the different soil and rainfall districts of the state should be made. In the 25th Annual Report of the Station to the Governor, attention was called to this matter as follows:

"On account of the great diversity of agricultural conditions found in this state, it is apparent that many of the

results obtained at the main station are not generally applicable in so far as these deal with soils and crops. It is very essential that the Experiment Station undertake additional investigations from the standpoint of crop rotation and soil fertilization under the various climatic and soil conditions of the state. This line of work, when conducted as it should be, would probably involve the establishment of six or eight experimental fields in different portions of the state. These, of course, need not be large, as the various experiments are conducted on twentieth and tenth acre plots. We have now available for this work land at the Adams Branch Station at Lind, and upon the farm at Waterville, thus giving us two locations for starting the work. We should, however, next year procure land for one or two additional locations in the western portion of the state."

Attention is also called to recommendations made in last year's report to the Governor, but which have not been acted upon, as follows:

"In addition to increasing our forage crop work, appropriations should be made for experiments with pasture crops—one of the great needs of Eastern Washington as an aid to the livestock industry.

"The critical condition of the horticultural industry of the state also calls for largely increased work in the field of entomology and plant pathology. There is urgent need for investigations upon the crown rot and mildew of the apple, also the leaf curl of peach, the brown rot of prunes and numerous fungous diseases of potatoes. In addition there are scores of other little known but troublesome fruit diseases which should receive early attention from the Station. A plant disease survey of the state should be undertaken and an increased amount of work is necessary upon the life history and habits of the codling moth, root maggots, orchard thrips, woolly aphis, rosy aphis and a large number of other insects causing devastation of farm crops in the state.

"Additional experiments are necessary to determine correct methods of spraying for the control of various insect and fungous pests." Several thousand dollars could be most economically expended upon such work.

The fruit by-products investigations should be materially expanded in order to meet increased need for utilization of our low-grade and surplus fruit.

The manufacture of flour and bread from our peculiar wheats, calls for considerable amount of investigation, some very valuable of which, has already been completed. We have, however, arrived at a point in this work where expansion of the Station facilities are greatly needed and appropriation for increased facilities along this line is strongly urged.

The Station should also increase its investigations of the possibilities of the manufacture of grain bags from Washington-grown fibre. The high price of bags the past few years makes this even more imperative than previously.

In the field of dairying, investigations are needed in cheese manufacture and costs of producing dairy products in the different agricultural districts of our state. Also, as called attention to in the previous Station report, there is needed "a considerable amount of experimentation with silage, both from the standpoint of production and feeding. Calf-feeding experiments with substitutes for milk are necessary as an aid to our rapidly developing dairy industry, as is also investigations in connection with Pasteurization of milk."

Washington is, and always will be, a great cattle and sheep range country. Extensive investigations are needed, looking to the more economic utilization of the range and the co-ordination of range use with the production of the adjacent districts of more intensive agriculture. The handling of the poisonous plant problem upon the range calls for considerable study.

The Experiment Station has, for the past dozen years, conducted investigations upon the life history and control of the ground squirrels. Valuable information along this line will shortly be published and it is strongly urged that funds be provided for continuing this line of work with other destructive mammals of the state.

Probably the most important problem confronting the Experiment Station today is that of control of wheat smut, which causes a loss of over $10,000,000 annually to the state. Fortunately the Station Pathologists have discovered methods of control of this pest and it now remains for the Station to devise means of putting these methods into practice. To do this, there is especially needed some investigation in connection with the mechanical collection of smut from thresh-

ing separators. The state can not afford to allow this problem to rest at this point, but should see to it that adequate means are provided to finish the work. The elimination of this pest from our grain-growing districts will result, annually, in a saving sufficient to pay the total expenses of the entire state government with a liberal amount left over.

In connection with the lines of work already under investigation, there is not a department that is not greatly cramped and restricted in its work for want of funds. Unless increased financial support is forthcoming, the Station shall be obliged to greatly restrict its field of work.

The Station library should receive very substantial additions, if the investigational work is to go forward with efficiency and economy.

Attention is also called to the fact that the salaries of Station investigators are far below those of other Stations and also below those of other members of the College Staff. The increase in cost of living has been attended by an increase in wages to laborers and in income to non-salaried men, however, the salaried man has been left to meet this increased cost with his old income, and it will be impossible to hold our better investigators in the state unless provision is made for future increase in salaries.

In connection with the question of state support to agricultural investigation, attention is called to a comparison between such support given by our neighboring states and Washington for this line of work. The following table is compiled from information furnished by the officials of the respective institutions:

TABLE V.

State	Ag. Investigation. Avge. Annual Appropriation from State Funds for 6 Years	Sta. Income from Sale of Produce	Assessed Valuation of Property†	Population
Idaho	$10,766*	$3,758*	$168,000,000	411,000
Montana	63,333*	7,250*	347,000,000	446,000
Oregon	47,517‡	13,619‡	905,000,000	809,000
Utah	15,000‡	3,000‡	200,000,000	424,000
Washington	9,933*	445**	1,005,000,000	1,471,000

*1911-1917.
‡1910-1916.
†From The American Year Book, 1915.
**1911-1915.

It will be noted that while Washington has the largest population and the greatest assessed valuation of the five northwestern states, nevertheless it is lowest in the actual amount of state funds appropriated for agricultural investigation and when the amount is compared, on the basis of assessed valuation in the different states, it can readily be seen that the State of Washington is doing relatively nothing for investigational work upon its most valuable and basic industry.

TABLE VI.

Amount Appropriated from State Funds for Agricultural Investigation, per $100,000 of Assessed Valuation of Property, in the Five Northwestern States.

(Average for past six years).

Washington	$ 9.88*
Oregon	52.50
Idaho	64.08
Utah	75.00
Montana	182.51

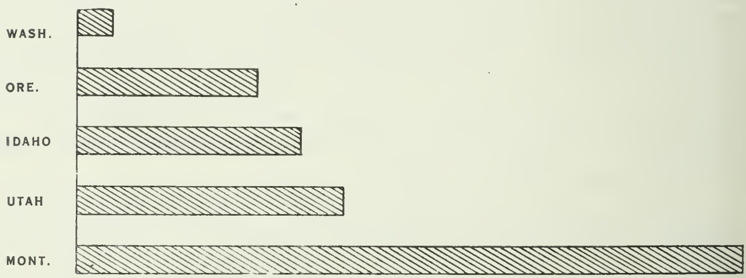

Fig. XVII. This graph illustrates the relative appropriation of state funds for agricultural investigations by the five northwestern states—an annual average for a six-year period, based upon the assessed valuation of property in the respective states.

In other parts of the country the same comparison may be made. Kansas, for example, has a population and area approximately the same as that of Washington, yet for the past six years the state of Kansas has put into agricultural investigation an average of $86,585 per year, **from state funds.** During the year 1916, the amount of state funds put into

*This does not include a small amount of the funds at the Puyallup Station which may from time to time be expended for experimentation. The major portion of the funds of this station are used for extension and the inclusion of the above mentioned funds in the table would not change the relative positions of the institutions with reference to state support for agricultural investigations.

this work in Kansas was $114,929; the year previous, $106,-569, yet Kansas with its relatively uniform climate and topography, has not one-third of the agricultural problems calling for investigation as has the State of Washington.

In other words, the Washington Experiment Station has, thruout its entire history, been conducted virtually upon funds furnished by the Federal government only. Recently the Federal government has placed certain restrictions on the use of these funds, confining their use very largely to research and publication of the same. Neither is it allowable to use the Federal funds for the general maintenance of sub-stations. Thus the station is left with a large amount of miscellaneous work of the state, such as soil analysis and the examination of various other agricultural materials requested by the citizens of this state, the investigations of special local problems such as an outbreak of pests or diseases, and also the large amount of chemical and biological work required by the state law upon sprays and spray material. There are virtually no funds with which to carry on this work, since the meager amount of state appropriation is insufficient to carry on the work of the sub-stations.

The Station has been severely criticized in the past for not handling the above mentioned types of work in a satisfactory manner, yet practically the entire difficulty arises from lack of funds for handling such work. Unless adequate funds are provided, responsibility for future failure in these lines will have to rest squarely with the state authorities for not providing funds.

In order to meet the needs herein discussed and carry this program thru the biennium, there would be needed an appropriation, from state funds, of $230,000.

The following is a list of some of the more important lines of work which should be taken up or increased by the Station, together with an estimate of the additional cost of each for the biennium:

Irrigation Station	$30,000
Logged-off Land	9,000
Marketing	14,000
Dry Land Work	23,000
Cranberry Investigations	6,000
Soils Work	27,000
Forage Crop Work	13,300

Crop Pest Survey and Horticultural Investigations	17,000
Spraying	3,000
Flour and Bread	6,000
Animal Diseases	11,000
Dairying	4,400
Range Investigations	3,400
Wheat Smut	5,000
Grain Bag Manufacturing	6,000
By-products Work	6,000
Library	4,000

SUMMARY OF PORTION OF STATION WORK

Number of projects under investigation	47
Number of pounds of new and improved seed distributed	43,122
Number of trees distributed	6,700
Number of newspapers and journals supplied with material	630
Editions of bulletins issued:	
Technical	10
Popular	11
Newspaper	31
Number of names added to mailing list during the year	2,495
Number of names on mailing list	29,906
Number of bulletins distributed upon special request	49,505
Number of pages of printed matter distributed	5,779,250
Number of personal letters written in reply to inquiries	20,000

DONATIONS AND OTHER ASSISTANCE

The Experiment Station has, during the year, been the recipient of a number of donations from citizens or organizations of the state interested in agricultural investigations, as listed below. Acknowledgment of the receipt of these contributions is made with a deep sense of gratitude and sincere appreciation on the part of the Station of the generosity and active interest on the part of the doners in the Station work.

Donations.

Adams County, for dry land investigations	$6,000
Chicago, Milwaukee & St. Paul Railroad, for dry land investigations	1,000
Committee of Spokane Business Men interested in dry land investigations	3,200
William Anderson, Winthrop, for investigations in animal diseases	1,000
Burke-Lehman Orchard Company, Twisp, Washington	125
Mitchell-Lewis-Staver Company, one wind mill	225
Benton County, for weevil investigations	500

Waterville School Board, free use of 60 acres of land for 25 years, for forage investigations.

The American Steel and Wire Company, 40 rods of iron fencing.

Great Northern Railroad, free freight in connection with stock disease investigations.

O.-W. R. & N. Railroad, free freight in connection with stock disease investigations.

W. C. Hanks, Winthrop, Wash, 15 sheep.

R. C. Garrett, Twisp, Wash., 1 hog.

FINANCIAL REPORT

	Hatch Fund Dr.	Hatch Fund Cr.	Adams Fund Dr.	Adams Fund Cr.
Receipts from the Treasurer of the United States appropriations for the year 1915-1916	$15,000		$15,000	
Salaries		$ 7,987.44		$ 8,799.80
Labor		1,581.42		3,070.07
Publications		2,037.13		
Postage and stationery		509.63		41.99
Freight and express		108.91		134.55
Heat, light, water and power				297.10
Chemical and laboratory supplies		210.71		293.94
Seeds, plants and sundry supplies		275.48		134.19
Feeding stuffs				598.35
Library		226.51		
Tools and machinery		68.31		287.92
Furniture and fixtures		401.97		6.00
Scientific apparatus and specimens		207.09		199.82
Traveling expenses		1,365.40		387.75
Contingent expenses		20.00		
Buildings and lands				748.52
	$15,000	$15,000.00	$15,000	$15,000.00

There was appropriated, in addition to the above, $19,000 from state funds for station work.

The following bulletins are available for distribution. They may be had without cost by addressing Agricultural Experiment Station, Pullman, Washington.

General Bulletins

74. Two Insect Pests of the Elm.
78. The Goat Industry in Western Washington.
79. Steer Feeding Under Eastern Washington Conditions.
91. Weat and Flour Investigations—Crop of 1906-1907.
100. Wheat and Flour Investigations—I. The Crops of 1908-1909. II. The Composition and Milling Quality of Washington Wheats. III. A simple Apparatus for Determining the Milling Qualities of Wheats.
102. Wheat and Flour Investigations. IV.
107. Plant Diseases Induced by Sclerotinia Perplexa.
110. Commercial Fertilizers.
111. The Chemical Composition of Wheat.
117. Report on Fires Occurring in Threshing Separators in Eastern Washington During the Summer of 1914.
121. Washington Wheats.
122. A Study of Grazing Conditions in the Wenaha National Forest.
123. Time and Method of Tillage on the Yield and Comparative Cost of Production of Wheat in the Palouse Region and Eastern Washington.
124. Bud Weevils and Other Bud Eating Insects of Washington.
126. Bunt or Stinking Smut in Wheat.
127. Twenty-fifth Annual Report.
128. Forage Crops in Central Washington.
129. Oats in Washington.
131. Evaporation of Apples.
132. Isolation and Cultivation of Bacterium Tuberculosis on a Synthetic Culture Media.
133. A Soil Survey of the Proposed Palouse Irrigation Project.
134. Sheep Husbandry in the Pacific Northwest.
135. Inheritance in Wheat, Oat, and Barley Hybirds.
136. Twenty-Sixth Annual Report, 1915-1916.
137. The Coulee Cricket.
138. First Annual Report, Adams Branch Experiment Station.

Popular Bulletins

29. Milling Quality of Washington Wheats. II.
36. Field Peas on a Palouse Wheat Farm.
39. The Milling Quality of Washington Wheats. III.
42. Alfalfa Seed Production.
47. How to Make Bread from Soft Wheat Flours.
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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF ENTOMOLOGY AND ZOOLOGY

The Coulee Cricket

By

A. L. MELANDER

and

M. A. YOTHERS

BULLETIN No. 137

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THE COULEE CRICKET

(*Peranabrus scabricollis* Thomas)

PART I.

GENERAL DISCUSSION AND PHOTOGRAPHS

By A. L. Melander, Entomologist

The following account is based on observations of one of the most spectacular of insects by the two authors, carried on in the native home of the coulee cricket as well as in the insectary of the Experiment Station. Previous to this study the Washington Experiment Station has had the insect under investigation since the first reported outbreaks in 1899, when Professor C. V. Piper and later, Professor R. E. Snodgrass, undertook a life history and experimental study of the species. Their publications are listed in the bibliography concluding the present account.

Fig. II. Cold Spring Coulee; one of the larger coulees. The 1915 visitation of crickets came from the banks on the right.

With the close of the Glacial Epoch the enormous torrents of melted snow pouring across what is now Central Washington, coursed through huge preexisting canyons. The formidable Columbia River then flowed as several branches in a south-westerly direction walled in by precipices of basalt rock, some of them hundreds of feet in height. With the recession of the ice sheet these ancient and temporary water courses became dammed at their northern end and the Columbia River resumed its majestic curve to the west, which forms the "Big Bend" country of Central Washington.

The now arid canyons, of which the greatest are named the Grand Coulee and the Moses Coulee, are characterized as waste stretches of "scabland" country, in their hushed solitude an impressive antithesis to their postglacial tumultuous history. During the summer there is almost never any rain and the parched ground supports only such rugged plants as sage brush and grease wood. Here and there depressions fill with rain-water in early spring and sometimes permanent land-locked lakes of densely alkaline water occur. The coulees themselves cover hundreds of square miles and the plateaux between comprise alternate stretches of arable wheat land and desert scab.

Fig. III. A small rocky coulee near Stratford, Washington, in the breeding area of a band of crickets. Such districts are too uneven to permit driving through with plow or spray-outfit to destroy the young insects.

Such is the home of the coulee cricket, a peculiar, large, lubberly, cricket-like creature, remarkable for its instinct to migrate for miles in hordes of millions of individuals.

The word "coulee," probably derived from the French verb, *couler*, meaning to flow, is in local use in the Northwest for any dry water course, small as well as large. In the southwestern states similar locations are known by the Spanish term *arroyo*. Technically, a coulee differs from a canyon in having sloping in place of precipitous sides, but local usage does not maintain this distinction. Some of the smaller coulees are rough and rocky, making it impossible to plow-under cricket eggs or to drive through with a spray outfit, methods elsewhere in common vogue for the control of similar insect pests. Sometimes the coulees are gentle draws through which the crickets advance during their migrations, but even the steep walls of the larger coulees are ascended by the insects.

Central Washington is in that belt of little rainfall termed by the older geographies as the "Great American Desert." Much of the district is waste land, rocky outcroppings of disintegrating basalt; much is unreclaimed but fertile soil; the remainder, an annually increasing amount, is devoted to farming and orcharding, but too often comprises isolated ranches, bounded by the vast cricket area.

Fig. IV. The sage brush desert in early spring. The large sage of the foreground grows nearly waist-high. Crickets are not found breeding here, but amid the talus and scabland toward the cliff.

Fig. V. An isolated ranch at the edge of the vast scabland.

The presence of the coulee cricket in the stretches of waste land is a menace to the interspersed ranches, for the crickets migrate when nearing maturity, traversing miles, although in no predeterminable direction. Owing to the sparsely settled condition of the country the task of intercepting the invading crickets from the small percentage of tilled land has been considered a community problem, and rather than let an isolated rancher battle alone the neighbors and townsmen have come to his aid. Funds have been furnished by the County Commissioners, amounting to five thousand dollars in

Fig. VI. *Artemisia rigida*, the scabland sage brush, in dormant (lower figure) and vegetative (upper figure) condition. The fallen needles at the base of the plant are so much sought by the crickets as a protected hiding place that the plant may well be called the cricket bush.

1915 and about fifteen thousand dollars in 1916, which have been expended for materials for the cricket warfare, the citizens supplying the necessary labor. Under the direction of the County Agriculturist, H. W. Reaugh, certain days during the greatest menace were designated "cricket days," when ranchers and townsmen from Coulee City and Ephrata to Krupp interrupted their own work to assist in checking the beginning migration of the insects.

Among the several species of sage brush, *Artemisia*, is one, *A. rigida*, the "scabland sage brush." This dwarfed plant, unlike the commoner larger sage brush of the fertile soil, is deciduous, shedding its needle-like leaves to form a felted mat under its gnarled stalks. In early spring baby crickets huddle by the hundred among the little leaves for protection against night frosts. Even when the crickets are half grown they still show a preference for this plant and in their later migrations and egg-laying their association with *Artemisia rigida* is noticeable. In a survey of miles of cricket territory at hatching time last March, scarcely a cricket was to be found about any other plant than the scabland sage, although this does not imply that every group of this plant was populated with crickets.

Fig. VII. Male of the coulee cricket. Enlarged about twice.

The physiographic environment of *Artemisia rigida* is characterized by poor soil. The plant does not occur on arable ground, where it is markedly replaced by *Artemisia tridentata* Hence the appropriateness of the term ''scabland sage brush'' for a ''scab'' is typically a protruding area of disintegrated lava. It is not in the rocky areas, but where the ground is covered with small pebbles as, for example, below a talus slope or in a washed-out draw, that the dwarfed sage occurs. The scabland sage, the pebbly surface, the noteworthy absence of the large sage, *Artemisia tridentata*, together indicate an area liable to be sought by egg-laying crickets, where later an invasion is likely to originate.

The coulee cricket (*Peranabrus scabricollis*) technically is not a true cricket, as it differs structurally in having four instead of three joints to its feet and in possessing a sword-shaped egg-laying tube in place of a needle-like ovipositor. It was described by Professor Cyrus Thomas in 1872, from specimens labeled Southern Montana at an elevation of about 8000 feet. The coulees of Washington belong to the arid Upper Sonoran life zone and average but little more than 1000 feet

above sea level, or about 1000 feet lower than the wheat-producing plateaux. Although the divergence in habitat is remarkable between the dry-land, low-lying coulees and the ridge of the Rocky Mountains, the insects of the two places are apparently identical. For some strange reason the species has never been positively recorded again in Montana,* nor elsewhere than the few restricted regions in the Big Bend country of Central Washington and once in the Blue Mountains toward the Oregon state line; although quite similar though quite distinct species occur in other parts of the Pacific Northwest.

When fully grown the coulee cricket is a heavy-bodied, clumsy insect measuring quite one inch in length, with an added inch in the female sex for the ovipositor. The females have the most rudimentary and useless of wing-pads and the males likewise possess small malformed wings whose sole function is to produce the chirping sound with which the males signal at mating time.

The coulee cricket is not the only insect that appears in destructive migrating armies. In many districts, particularly in Southern Idaho, Nevada, Utah and Colorado, bands of the mormon or western cricket (*Anabrus simplex*) periodically occur, and their invasions and destructive habits closely resemble those of the coulee cricket. Other species of these wingless locusts are found in the West, but so far they have not been so prolific as to be of much economic importance.

The life of the coulee cricket is divided into seven stages, or instars, which are separated from each other by molting processes, at which time the insect sheds the skin from its entire body. When hatching from the egg in early March, the crickets measure scarcely one-fourth of an inch in length and are delicate, almost helpless creatures. After a week of nibbling at the "sheep grass" which grows among the sage brush they arrive at the time for the first molt, following which they become a size larger than before. This method of growth is

*Professor R. A. Cooley in the 13th Ann. Rept. Mont. State Ent., p. 151 (1916), reports the species from the Flathead Indian Reservation, but later, in litt., is not entirely positive about the determination. The writer, in motoring through the Reservation in August of this year, failed to notice any *Peranabrus*, although he found *Anabrus simplex*, var. *maculatus* in the vicinity of St. Regis, near Ronan, where Professor Cooley's specimens were taken.

Fig. VIII. *Anabrus longipes*, a relative of the coulee cricket, which occurs at Pullman, Washington, and has not been found elsewhere. Enlarged twice. Another species, *Anabrus simplex*, known as the western cricket, is widely distributed and often occurs in immense armies.

repeated three times, whereupon the insects, now in the fifth instar, begin to manifest their remarkable migratory instinct.

The females even early in life can be distinguished from the males in possessing a visible ovipositor or egg-laying tube. At the third instar the ovipositor measures about one-sixteenth of an inch in length and doubles in size with each molt. Hence it is convenient to identify the stages by the length of the ovipositor as, for instance, the half-inch ovipositor indicates the penultimate or sixth instar.

Fig. IX. Progressive growth of the coulee cricket. Upper row female; lower row male. Almost natural size.

When a week or ten days old and molting time approaches, the infant crickets ascend to the end of a branch of some of the dwarf desert shrubbery, and, facing downward, obtain a secure hold with their legs in preparation for this momentous occasion (Fig. 1).* After a few minutes of straining the skin splits behind the head and slowly the rent enlarges until the back of the insect begins to protrude (Fig. 2). Then by a series of contortions, wriggling to the right and left, the insect gradually works itself loose from the old skin (Fig. 3). Now becomes apparent one purpose of the backward-pointing spines on the legs, for with each wriggle the legs are withdrawn one notch further from their old casing. Finally, when the legs and feelers are freed, the cricket hangs head downward, resting from its labor (Fig. 4). About twenty minutes from the beginning of the process the insect catches hold of the supporting twig (Fig. 5) and tugs itself free from the old shell (Fig. 6). It now appears slightly larger than before the molt, is extremely delicate, with pink-colored thin skin which

*See Fig. X., p. 14, 1—8.

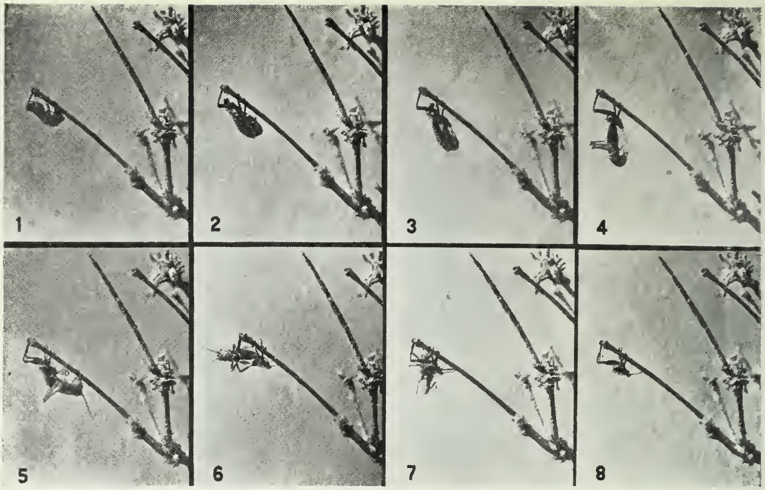

Fig. X. The first molt, natural size.

pulsates and bends with the pulling of the muscles within (Figs. 6, 7). Even the jaws indent readily. After a short rest the cricket drops to the ground, leaving its spent shell attached to the twig (Fig. 8). A half-hour of sunshine blackens and hardens the new covering so that the insect is enabled to resume its interrupted activities. The technical term for this process of molting is ecdysis, a Greek word which, freely translated, means ''slipping off one's shirt.''

During the earliest periods of the crickets' life their time is spent in a very uneventful manner. All night and through the cool hours of morning the crickets remain bunched together in the midst of the leaf-needles underneath the sage plants. Here they may be uncovered fifty to several hundrd to each bush. As the day warms up the crickets emerge, hop about to nibble on the sheep grass and thus they spread out from the hatching site. Very little food suffices at this stage and the crickets are rarely to be observed feeding, although the chewed edges of the grass attest the appetites of the insects. The crickets are very fond of buds and blossoms and hence a bed of desert violets in flower is a good indicator of the absence of crickets. During the first and second instars ordinary noises are not perceived, but when migrating and later the crickets jump in alarm at such sounds as metallic clicks, an inspired clacking whistle, hand claps, etc. While

XI. Upper row: crickets in the fourth instar, taken in April on the breeding ground. Lower row: crickets in the fifth instar, taken the same day from a migrating band. Illustrating the stage of growth when the migratory instinct becomes manifest. Nearly natural size.

susceptible to these noises they pay no attention to calling, singing or an expired whistle. Even before the crickets are able to chirp they communicate their excitement until jumping becomes universal for several yards around and the little insects are scampering for shelter. Then they hide under the sage brush or alongside some clump of sheep grass and even though in full view their thigmotropic instinct quiets their alarm.

What are the factors that prompt the instinct to migrate and what are the factors that determine the direcion of migration? It is commonly supposed that the crickets, being overcrowded, disperse to new grounds because impelled by hunger. However, at the time of the fifth instar, when the migration begins, the desert is blossoming with vegetation.

The coulee cricket is markedly gregarious and seeks companionship. Groups numbering from dozens to hundreds congregate at night beneath the scabland sage and during the day in open sunny spots. Here and there in the open, whereever bands of crickets have remained stationary, can be seen piles of excrement-pellets attesting the previous presence of crickets massed together for hours at a time. The slightest

Fig. XII. In the midst of a stationary band of crickets. Natural size.

disturbance causes the crickets to scatter and, their alarm spreading, instantly a multitude of crickets are scampering for shelter. This habit, which is allied to the synchronism manifested by some other insects, coupled with their custom of daily wandering away from their sleeping quarters, accounts for the initial dispersal from the breeding grounds.

At the middle of March a band of newly hatched crickets was kept under daily observation a mile north of Stratford. This band was localized on about an acre of typical scabland. A month later the breeding ground was deserted except for a few undersized crickets, the nearest band of normal individuals being a quarter of a mile to the west, having traversed to the sage brush region beyond the scabland.

It seems that a very small occurrence might start a big migration. When the crickets start going they continue with the majority, and, their numbers being augmented, an army or drove is on the way.

The direction of the migration may likewise have been decided by some trivial circumstance. Apparently the route is not determined by the sun, by gravity, by the wind, by the directions of coulees, or by the presence of desert scab or fertile wheat-land—theories advanced by ranchers and others. Sometimes crickets move **down** a coulee; sometimes they climb **up** the walls of a canyon; sometimes they move to

Fig. XIII. The crickets may congregate until they jostle each other.

the north, or south, or east or west, or to any intermediate direction. Sometimes the direction of movement of an army can be changed, as by herding, or by the presence of hogs or turkeys, or by trenching or fencing, or when the crickets meet an irrigation ditch or stream. In the last instance the advancing crickets are pushed into the water by those behind and are forced to swim over, to continue the migration in reduced numbers.

A prevalent idea is that crickets hatch in several broods. This is due to the successive migrations that sometimes pass a given point, the crickets coming from different breeding sites rather than being of different ages. Although egg-laying continues for six weeks or more, the vast majority of the crickets hatch within one or two weeks of each other.

Although the crickets manifest a decided preference for each other's society, yet it is purely impersonal. They do not recognize the individual but are interested in the species. A cricket in distress arouses no ethical response. Instead, if one is wounded his nearest neighbor will leisurely proceed to feed on him. The most grewsome sights are common: disembowled crickets drag along until pounced upon by others; it is not unusual to find several cannibalistic crickets devouring a disabled but still living and weakly protesting individual.

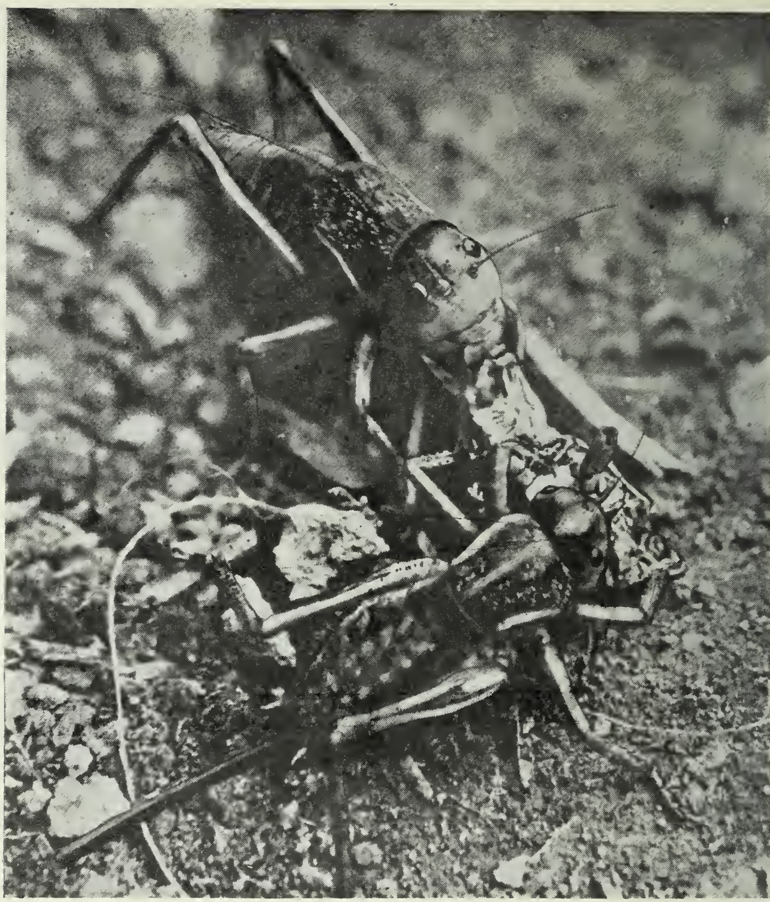

Fig. XIV. Two cannibalistic crickets devouring one of their fellows. Twice natural size.

In close quarters, such attention may lead to mutual nibbling at each other's appendages, which is probably made possible by a minimum sensation of pain.

When the crickets have reached the seventh and final stage of growth they are sexually mature. Then the males begin the shrill chirping produced by the rapid vibration of their miniature wings, which serves partly at least for courtship purposes. When a pair of crickets are about to mate the male commonly intrudes his abdomen beneath his mate's and seizes hold by a pair of claspers located at the end of the body.

Fig. XV. Female cricket receiving the seminal sac from the male. Although crickets manifest little sexual interest in the afternoons they are commonly found courting and mating during the morning hours. The cerci of the males are curiously modified as clasping hooks and are used to seize the female from beneath.

After a few minutes fertilization has taken place whereupon a large bilobed globular mass of white albuminous matter is emitted from the accessory glands of the male genitalia. This is gripped by the bursa copulatrix of the female, to serve, as Snodgrass says, in closing the orifice of the bursa. However, the interior of this mass contains virile spermatozoa, so it probably functions in part as a spermatheca. The extraction of the mass from the male abdomen is accomplished by the female pulling at it. When finally copulation has been effected the sexes separate and the female goes about for many minutes with her abdomen elevated, apparently to keep the sticky albuminous mass from becoming soiled, although if the mass be removed she still holds the abdomen up. Within a half-hour the females invariably reach down under the body and eat off the mass, sometimes being assisted by nearby crickets in this performance. The coulee cricket is salaciously and indiscriminately polygamous, and even may mate on successive mornings.

Fig. VI. Female cricket laying eggs.

Crickets do not lay all their eggs at once. Several dozen eggs in the lower tubules ripen first and are deposited in the soil one at a time. The egg-laying cricket is very deliberate in selecting a proper spot for oviposition. Sometimes she decides on the pebbly surface of the soil and standing horizontally works the end of the ovipositor down a quarter of an inch or more, the egg then gliding down between the blades of the ovipisitor. When this egg has been thus vertically placed she pokes about for another spot and so proceeds. Sometimes she holds on to a bit of brush or sheep grass and, standing almost erect, inserts the ovipositor straight down, even for its entire length, if the ground is soft.

Gravid females undoubtedly exercise a selection in choosing the spot of ovipositing. The area is typically that pebbly ground marking the habitat of the scabland sage brush, and during their migrations the egg-laying females stop to oviposit when traversing such locations. Eggs laid elsewhere are relatively few in number, due to hurried marches through less favorable country, a fortunate circumstance for self-preservation, for young crickets readily perish if deprived of shelter in the spring, whereas the fallen needles of the scabland sage afford the best of shelter. Although eggs laid in cultivated fields may hatch the young crickets are likely to die from exposure.

It has been claimed that only those crickets remaining behind in the coulees and on the home breeding grounds on the scabland, those that do not manifest the migratory instinct, alone perpetuate the species, a habit which might

Fig. XVII. Eggs of the coulee cricket. Inserted figure: the egg parasite and some parasitized eggs. Enlarged nearly three times.

eventually lead to a hereditary cessation of migration. However, the facts do not warrant this assumption, for sufficient eggs are laid on barren ground encountered on the march to provide for multitudes of crickets all endowed with the migratory instinct.

Grasshoppers lay their eggs in pods of several dozen, but the coulee cricket deposits them one to a place. For this reason and because of the rocky districts where the eggs are laid, plowing of the ground to control the insect can not be practiced. The eggs are protected by a remarkably tough, leathery skin and are brownish in color, measuring three-sixteenths of an inch in length. Their vitality is surprising; an instance was cited where in a depression of the land eggs were inundated for weeks in early spring, yet hatched later. On March 16, seventy-five eggs dug out from a two-inch square in typical scabland near Stratford, showed fifty already hatched and most of the remainder in moist, living condition. When hatching, the end of the egg splits open and the pinkish infant cricket slowly wriggles out. The hatching season may come even before the winter snows are gone, in which case the baby crickets are exposed to rigorous hardships. The western

Fig. XVIII. A mummied cricket found in March among the grass, where it died the previous year.

cricket, *Anabrus simplex*, is stated to survive severe freezing, but the cricket of the coulees is harmed unless protected under shelter. Following the night freezes the crickets are stiff with cold and move sluggishly until well warmed by the sun.

Among the eggs gathered this spring were some parasitized by a Scelionid wasp. This egg-parasite has been determined through the courtesy of Professor C. T. Brues of Harvard University as *Sparaison pilosum* Ashmead.

* * *

Born in the back-country in March, nurtured in the desert of sage brush during April, traversing, in unnumbered hordes, miles of country during May and June to devastate whatever fields may be in their pathway, and finally to die so that only a few straggling individuals remain alive into July, such is the life-round of the coulee cricket. From July to the following March no sign of the visitation is to be seen unless one searches among the dried grass when an occasional spent carcass can be found. The species has run its course for the season; the innumerable eggs safe in the ground tide the insect over to the coming year.

Fig. XIX. Experimental kerosene-spraying of newly hatched crickets as they cluster about the small clumps of scabland sage.

CONTROL

The simplest way of attacking the crickets is to destroy them when very young, for as they become older and spread out from the hatching site they become increasingly harder to reach and to kill. By patrolling the migration routes in May and June to mark the egg-laying districts or during the following March to note where the young are hatching it is easily possible to locate the restricted breeding areas. A few acres will probably have practically all the crickets that later spread over a square mile. When the young crickets hatch they may be destroyed by several methods, one of which is to spray with kerosene emulsion.

During the warm part of the day, when the crickets have emerged from their hiding places under the shrubbery, they can be readily slaughtered by a light spraying of emulsified kerosene. On the more level scabland this may be applied by a mounted spray pump. While a five to ten per cent emulsion will answer for the first instar, it will have little or no effect on crickets past the second molt.

Fig. XX. Using the blast torch. Any crickets not hidden in the midst of fallen leaves of the sage brush are immediately incinerated by the flaming gasoline.

By means of a large gasoline-burning blast torch, such as the one illustrated above, obtained from the Turner Brass Works, Sycamore, Illinois, the small crickets can be surely annihilated. This implement, belching forth several feet of flame, is particularly effective just before and just after the hot part of the day, when the crickets have congregated about the bushes but have not burrowed into the fallen leaves. The cost of operation is considerably less than with the spray pump, but the ground can not be covered so quickly as with the liquid sprayer.

Straw may be scattered in small piles in the breeding districts to entice the insects at night fall. By setting fire to the piles before the crickets leave the next day immense numbers can be destroyed. This method was largely employed in earlier invasions of crickets in Douglas County, but a scarcity of straw this year in Grant County made the treatment unpopular. Wheat growers are willing to import arsenic or gasoline, but not straw.

Fig. XXI. Mixing various poisoned baits in the field test of the value of insecticide control. (M. A. Yothers, photo.)

During the growing periods the crickets eat ravenously, consuming several times their weight of vegetation each day. Spraying the vegetation with an arsenical, however, is not regarded as practical, nor has it served to check the insects; but the crickets can be readily lured to moist poisoned bait. For this purpose fresh horse manure has proved very effective when mixed with one to two per cent its weight of sodium arsenate previously dissolved in sufficient water to make a paste of the droppings. The bait should be lightly scattered at the bases of the bushes frequented by the crickets. Arsenate of lead, arsenite of zinc, Paris green or white arsenic may be utilized in place of the sodium arsenate, but then care should be taken to have the manure uniformly mixed with the insoluble poison, and the stronger amount, two to the hundred, should be used. Manure is recommended because it is less likely to be attractive to birds and sheep than such baits as bran or shorts and because it is cheap and easily obtainable; while sodium arsenate is the quickest acting of poisons and being soluble will render the manure innocuous after the first rain. The addition of such condiments as salt, sirup, milk, oranges and lemons was tried one at a time, but their actual value is problematical. Later, during the migrations, poisoned baits will serve to decimate the crickets if scattered where the insects become massed.

Fig. XXII. Digging trenches to head off invading armies of crickets from the adjacent fields seeded to wheat.

In contemplating the helplessness of the isolated farmer to check the pest when the crickets literally pour into the cultivated fields, one is reminded of Mrs. Partington's classic task of sweeping back the ocean-tide. The control of the coulee cricket is not merely a matter concerning one man. The area to be covered is too great; the menace to the wheat fields extends far beyond those nearest the scabland; it is a community affair. Hence the necessity of co-operation in stemming the attacks of this insect army.

Fortunate it is that the coulee cricket is wingless and too lubberly to jump far. It advances in a slow walk and by short leaps, but its numbers progress for a dozen miles and more. If a trench or ditch about one foot in depth is dug across the path the crickets fall or are crowded into this, and rather than exert themselves to climb out again they remain in the trap. Sometimes, for preparedness, a second line of trenches is dug, although a single trench properly built and sufficiently manned, is amply effective in checking the present numbers of crickets. The off-side of the excavation should overhang slightly and be clean-cut, while weeds and obstructions in the ditch should be removed to minimize the chance of trapped crickets escaping. The earth dug out generally should be thrown along the side of the trench furthest from the army, for crickets dislike walking on the soft powder-like dirt and so if any climb out they are apt to fall back into the trench on reaching the dusty soil.

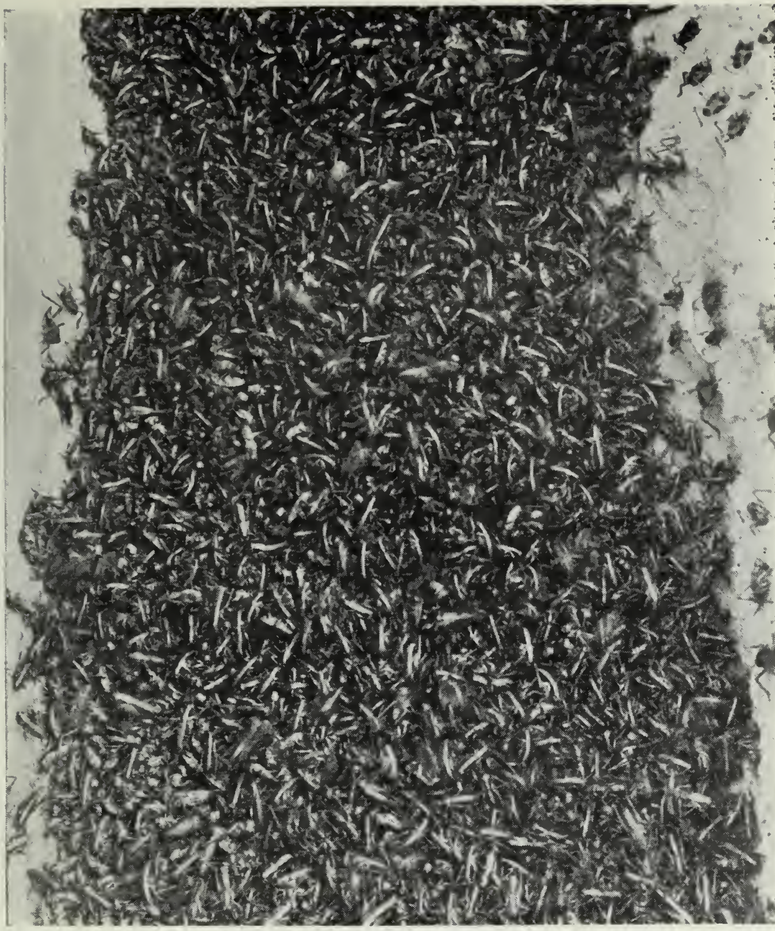

Fig. XXIII. Looking down into the bottom of a trench, showing the multitude of trapped crickets.

When a cricket falls into a trench it jumps several times in alarm and then, joining its companions, settles down to a slow march along the excavation. Thus the majority of trapped crickets are progressing in one direction. But when the invasion is at its height, following a spell of warm weather, the crickets pour into the trench, crowded and pushed over by their comrades gathering on the embankment. The trench quickly fills, and then instead of showing an orderly march the bottom becomes a black mass of angry, spitting, biting, kicking crickets, trapped, too bewildered to attempt escape.

Fig. XXIV. Workmen disregard the crickets which try to escape from the trenches by climbing over their clothing.

Those weaker or weakened are trodden under and suffocated by the stronger whose frantic actions serve only to extinguish each other's lives.

The effectiveness of trenching is assured by digging pitfalls, one to three feet in depth and extending across the bottom of the trench. If this is not done some of the crickets manage to ascend the walls and escape, but where pits are dug at intervals of twenty to fifty feet the insects fall into the new trap, where they quickly accomplish their mutual destruction.

The crickets trapped and smothered in the pits rapidly decay and give rise to an intolerable stench. Carrion beetles (*Saprinus*, *Dermestes* and *Silpha*) and blue bottle flies (*Lucilia*)

Fig. XXV. The pit soon becomes filled with a writhing mass of crickets.
Fig. XXVI. Using the blast torch to destroy crickets in the trench.

swarm to their feast and soon the crickets become converted into a wriggling mass of maggots and beetle larvae. Owing to the disgusting nature of the pit-contents workmen prefer to cover a filled pit with earth and construct another pit instead of emptying the old ones. However, if the pits receive daily attention the dead crickets can be strewn to one side and thus become dry without appreciable odor. Such dried insects should be of considerable value later as poultry food.

These pits are the most essential feature of the cricket warfare. In the trenches they materially lessen the number of attendants required to prevent the insects escaping, for they automatically catch, hold and destroy all that come.

A baker's dozen of the large insecticidal blast torches were used this season in the cricket warfare. By slowly passing the flame along the trenches and pits the crickets are either singed or burned to death. The singed individuals are pounced on by incoming crickets and destroyed, so the work

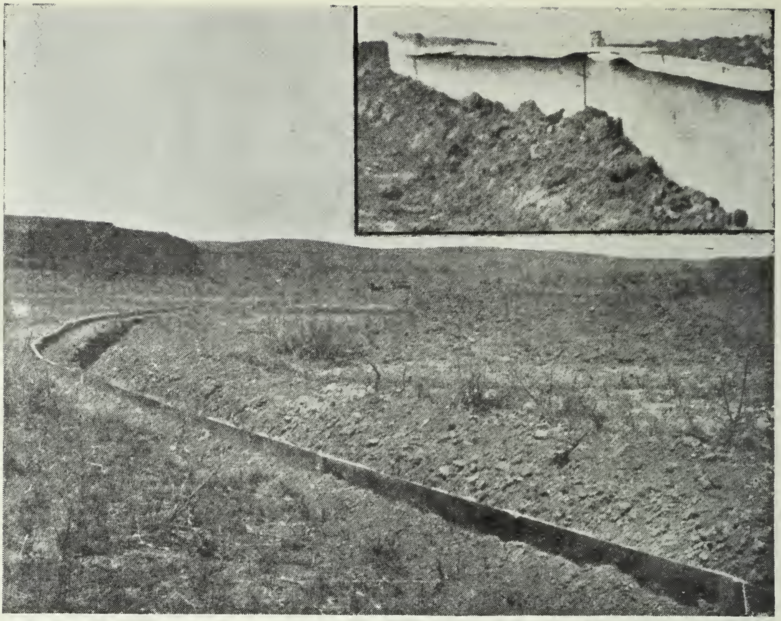

Fig. XXVII. The shiplap fence capped with projecting sheet iron. Insert: showing detail of construction.

of the torch is completed. Although the torches were used this season to burn crickets in the shrubbery and along the embankment, such labor is unproductive, for sooner or later these individuals would have reached the trenches and perished in the pit-traps.

Either as a supplement to the trench or used alone miles of cricket-fencing have been constructed at county expense to check the incursions of the coulee cricket. Eight-inch shiplap is commonly used, placed end to end, held in position on edge by small stakes, and capped with a projecting two-inch strip of thinnest galvanized iron. As the direction of future migrations can not be foretold the fence is built in a temporary manner, with nails driven in only part way, for easy dismantling. Crickets may climb the fence and may catch hold of the projecting tin but they have neither the strength nor the agility to pull themselves over.

Grant county, under the direction of County Agriculturist Harry W. Reaugh, this year constructed upwards of thirty-five miles of fencing and trenching, the longest stretch extending uninterruptedly for twelve miles.

Fig. XXVIII. Upper figure: showing the use of the deflector to guide crickets into a pit. This pit, when photographed in May, was filled with dead crickets from a migration of the previous week. The stench arising from the maggot-ridden mass was most nauseating. Lower figure: using a branch of sage brush to drive the crickets into a pit.

Crickets that manage to surmount fences or ditches and attain the fields beyond usually return at nightfall to join the main band. The gregarious instinct is strong.

When the advancing crickets come to a trench or a fence many of them swerve to the right or left and move along the obstruction. The interposition of a projecting spur of fence-lumber, set at an angle to the main barrier, serves as a deflector to shunt the crickets into pits dug at the intersection. Often it is worth while to arrange in the line of march boards in the manner of a widely open V, with a pit dug at the apex. Such deflectors are sure to concentrate the crickets into certain traps, and are important in that the success of the pit system is determined by the quickness with which the traps become filled and, correspondingly, the crickets become smothered. A branch of sage brush wielded by an attendant serves to herd the crickets toward the deflectors, although crickets as a band do not easily "shoo." Each individual may jump along for eighteen inches or so, but then becomes tried and refuses to move forward.

Fig. XXIX. Cricket-fence extending across a roadway.

Fig. XXX. The removable gate in the cricket-fence.

Where a cricket-fence crosses a driveway it is necessary to provide a gate. One section of shiplap can be made removable, but it, like the rest of the fence, must be banked with earth underneath, or the crickets will crawl through the openings.

At first automobilists were addicted to driving over such low obstructions in the road, which necessitated frequent repairing of the fence. The expedient of driving nails projecting through the board, however, put a quick stop to this misdemeanor.

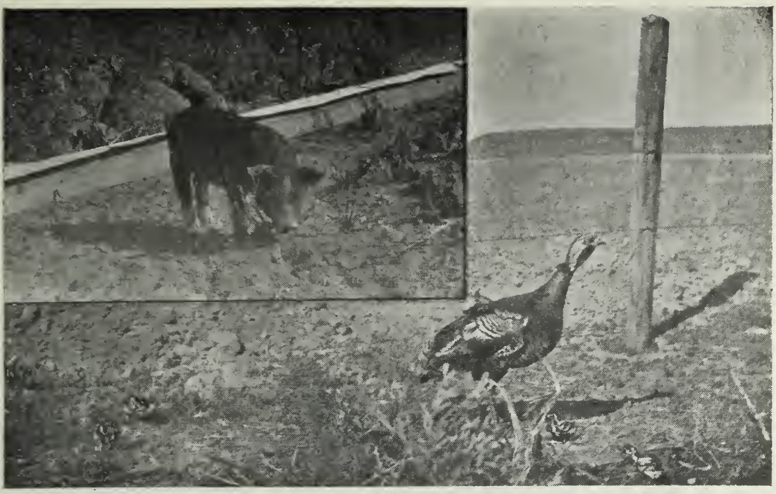

Fig. XXXI. Turkeys, young and old, and hogs gorge themselves on crickets. One herd of forty hogs was pastured by the county out in the sage brush desert with no other food than crickets. Three months later, when the photograph was made, the animals were fat and sleek, attesting the nutritional value of the cricket diet.

Although undoubtedly containing much nutrient material the coulee cricket is scarcely preyed on by enemies. Native birds pay little or no attention to them, as far as we have observed. During the earlier instars an insignificant few are destroyed by ants (*Formica rufa*), robber flies (*Cyrtopogon maculosis*) and ground beetles (*Calosoma zimmermanni*). The last mentioned gorges itself on cricket after cricket, but its numbers are too few to tell on the host. Even the fungus, *Mucor*, known as a grasshopper disease, does not take hold on the crickets, as was demonstrated by Professor C. V. Piper of this Station, in 1901 and 1903. This is rather surprising in view of the cannibalistic and gregarious habits of the insect.

On the other hand, hogs, turkeys and chickens are extremely fond of crickets. Even turkey chicks will catch and devour full-grown crickets. Chickens soon become satiated and, anyway, there are too many of the insects for the birds to make any impression on their numbers. Hogs learn to feast on the insects and will search for them where they are hiding under the sage brush. Against the fences and ditches, where the crickets are especially numerous, the hogs will gather and gorge themselves on the easily obtained and highly nutritious food.

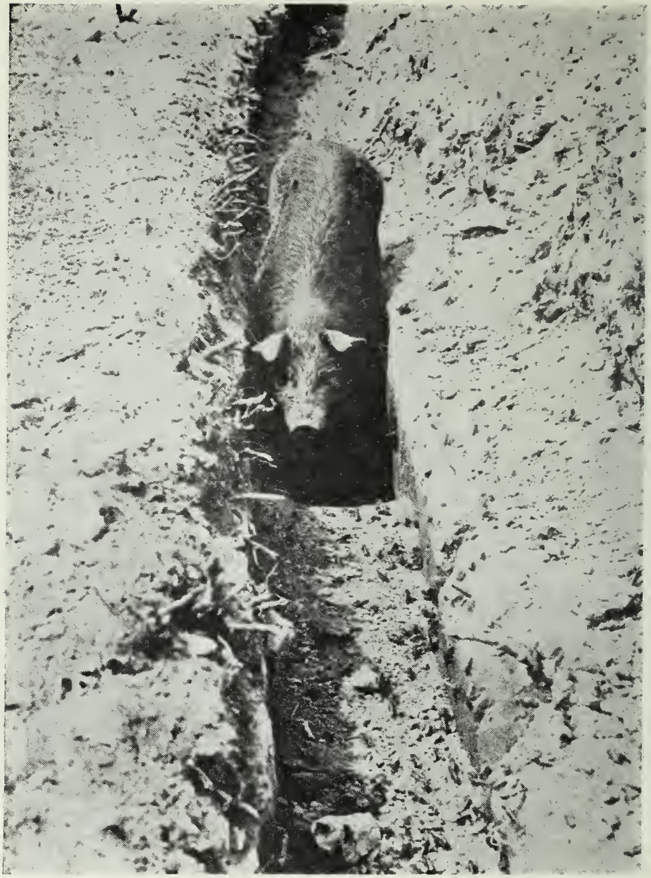

Fig. XXXII. Hogs wallow in the pits full of crickets.

This is not a pig in a poke, but a fat hog well in view, sitting in a trench, with fore legs in a pit and eating crickets as fast as they can be swallowed. At first such an over-plentiful diet results in a continual diarrhoea, a natural consequence of the liquid content of the crickets rather than following any irritation from their indigestible shells. However, Professor Piper has noted occasional more severe gastric disturbances, which he ascribes to the ingestion of so many chitinous ovipositors and spinose tibiae.

While the cricket situation has been locally of most serious consequence yet the district invaded is fortunately relatively small. *Peranabrus* is distinctly an insect of the desert, where it has lived for untold ages amid the dry Coulees. So far

Fig. XXXIII. A physiographic map of Washington by Dr. S. Shedd. The irregular lines drawn near the central part of the State (lat. 47°30', long. 119°10') indicate the principal fences and trenches constructed in the cricket campaign of 1916. The circle shows the place of origin of the outbreaks about fifteen years ago and the cross in the Blue Mountains the only other place, aside from Montana, where this insect has been found.

the insect has not advanced east of Wilson Creek or south of the line of the Great Northern railway. What is to hinder it from invading the miles of scabland west of Adrian, east to Odessa, or the south half of Grant county, a vast district of the same physiographic environment as its present habitat and amply provided with the cricket sage brush?

The earlier outbreaks of *Peranabrus* originated in the Badger Mountains, southwest of Waterville. Is the present invasion to the east comprised of direct decendants of the Badger Mountain insects or does their joint ancestry date back ages before, even to the progenitors of the bands in the Blue Mountains and the Rocky Mountains? With the crickets' habit of migrating to new territory the future outlook is ominous for the ranchers of the Big Bend country who live nearest the scabland. However, the extended warfare waged this year has certainly decimated the species so a recurrence of the present attack is not probable for some years to come. The coulee cricket can not be exterminated; but it can be held in practical control if sufficient labor is forthcoming.

PART II.

MISCELLANEOUS NOTES ON THE BIOLOGY OF THE COULEE CRICKET.

By M. A. Yothers, Asst. Entomologist.

INTRODUCTION.

The following miscellaneous records were, for the most part made in the Experiment Station insectary during the period from March 20 to August 15, 1916. The first crickets were brought into the insectary on March 20, when they were in their first and second instars, and the second lot was brought in on April 21, when they were in their fourth and fifth instars. The crickets were placed in breeding cages constructed of common flower-pots and glass chimneys and were reared through their various stages, some to maturity and some even until the last of them died on August 15. Much of what transpired during their development was not learned owing to the writer's absence during the greater part of the period up until June 12, but the few facts presented are deemed worthy of record inasmuch as they show certain characteristics and biological facts heretofore unrecorded.

FOODS, FEEDING, ETC.

Food Plants.

The coulee cricket is practically omnivorous, eating nearly every kind of plant that was given it. It is particularly fond of such luscious food as the foliage of beans, beets, cabbage, corn, potatoes, turnips, etc., but shows a decided dislike for the different kinds of peas—eating them only very slightly and as a last resort. Their reported dislike for field peas in their native habitat might prove of value as a control measure. In the insectary crickets in various stages of development fed readily on alfalfa, apple, beans, beets, cabbage, carrots, cauliflower, cherry, chinese lettuce, clover, corn, catalpa, dandelion, grass, lettuce, maple, mountain ash, oak, oats, onion,

parsnip, potato, pumpkin, radish, rutabaga, salsify, spinach, tomato, turnip and wheat. While newly hatched crickets refused cabbage those in the growing stages ate readily of this plant. Adults regularly refused to eat the foliage of lilac, maple, mustard, parsley, field peas, garden peas, sweet peas, pine and willow, even when deprived of food more to their liking.

Cannibalism in *Peranabrus scabricollis.*

Thruout their entire life the crickets are cannibalistic. In the field and in the cages in the insectary they have been observed feeding upon one another during each instar, both when food was scarce and when it was abundant. Although scarcity of food is no doubt conducive to cannibalism, it is not a necessary condition. Snodgrass (8, 1905) draws the inference that only the males kill and feed upon the females especially during the oviposition period. This inference is incorrect for thruout our five months' observation both sexes were killed and devoured in about equal numbers. During the oviposition period, it is true, relatively more of the females are killed and eaten. This may be partly due to the weakened condition of the females after oviposition although our observations have not indicated that the females are less vigorous than the males. The fact that the females are more or less fixed to a certain place while depositing eggs makes them more readily caught, and this may be the explanation rather than that they are weaker.

Crickets' Thirst.

One day a few drops of water were placed into one of the cages when it at once became evident that the crickets were very thirsty. They immediately scurried about, eating up greedily every available drop. After that they were given water nearly every day and they always seemed to be thirsty.

Length of Time After Molting Until Crickets Eat.

Crickets do not eat after the earlier molts for something like a day, but as they grow older they begin to feed within a few hours. A possible explanation for this is that when they molt from the earlier instars their mouth-parts are very soft and pliable and consequently require some time for hardening before they are in a condition to manipulate the food, but as

the crickets become older there is less softening of the mandibles after each molt and the mouth-parts are soon ready for use after casting the skin. Possibly newly hatched crickets not having the reserve store of energy possessed by older individuals require a longer period for convalescence after the physiological disturbance of molting, and hence are slower to partake of food, or possibly their sluggishness is a temperature reaction.

Weight of Crickets.

Eight female and eight male crickets were weighed on July 14, 1916, after the males had fertilized several females and after the females had oviposited for several weeks. The average weight was 1.733 grams for the females and 1.666 grams for the males. The females are therefore regularly somewhat larger than the males.

MOLTING

The Molting Process.

Only the first molt was closely observed, but it is quite probable that the process is, in general, about the same at each successive molt. A number of specimens were observed and one was timed for each stage in the process. At 10:40 A. M. on March 17 a certain cricket in its first instar walked up to the top of the small grass blade, turned about facing downward and fastened its hind tarsi to the grass upon which it stood. At 10:50 the pronotum began to split down the median line and gradually the old skin split apart wider and wider showing the light pink new skin underneath. By 10:53 the top of the head, the pronotum, and part of the eyes were visible in their new covering. At 10:54 the eyes were entirely free, the upper part of each soon became darkly pigmented; the left front leg and the left antenna then slowly came out. At 10:55 the head and mouth-parts were free of the old skin, the mandibles being soft and pliable so that they bent and collapsed when forced together. At 10:56 another leg was free. At 10:57 the eyes were both entirely free and pigmented, the fore legs free and the antennae both free. By 11 o'clock the four anterior legs were free. The

spines on the posterior side of the hind tibiae were used to help free the hind legs from the old skin. The cricket tilted its body slightly to one side when the edge of the cast skin just slipped past one of the spines on the leg on the other side of the body. By alternately leaning first to one side and then to the other it gradually, spine by spine, pried off the old skin, leaving the hind feet free . The hind femora were so soft that they bent greatly each time the cricket pushed back against the edge of the cast skin. At 11:02 the hind feet and the tip of the abdomen pulled free and the cricket stepped away, turned around facing upward on the grass and the molting process was complete. The molting process in this instance required in all about twenty minutes, but the actual shedding of the skin took only about one-half that time.

Time of Day When Molting Takes Place.

According to our records, part of which were taken in the field and part in the insectary, the molting process may take place any time between the hours of 8:30 A. M. and 6:00 P. M. Our observations have shown, however, that nearly all molting takes place between 10 o'clock A. M. and 5 o'clock P. M.

Time Required After Molting for the Crickets to Acquire Normal Color.

Both mature and immature crickets, for the greater part of the time during each instar, are of a dark reddish brown color, but just after each molt they are pink. There seem to be several conditions which determine the amount of time requisite for the recently molted crickets to recover the normal color. If they molt during the forenoon of a bright, warm day they regain their dark brown color by night, but if they molt in the afternoon they are but slightly colored the next morning. They gain but little if any color pigmentation during the night. If the day is cold, dark and cloudy but few crickets molt and those that do so color but slowly. During the later molts, when the sunlight is stronger and the temperature higher, the new skins gain their color much more readily than during the cooler spring.

TABLE I.

Life History of an Individual Cricket

Date	Molt, etc.	Remarks	Place
March 9.	Hatched....	....	Stratford, Wash.
March 17	First molt..	....	
March 26	Second molt.	Ovipositor 1 mm. long.....	Pullman, insectary
April 7..	Third molt.	Ovipositor 2 mm. long.....	
April 12.	Fourth molt	Ovipositor 3 to 5 mm. long	
April 18.	Fifth molt..	Ovipositor 6 to 10 mm. long	
April 25.	Sixth molt..	Ovipositor 20 to 25 mm. long	
May 1...	Mature.....	....	
May 21..	Mating.....	May have mated before....	
June 12.	Ovipositing.	May have done so before..	
July 1...	Died.......	....	

The preceding table shows the various stages in the life of a single specimen of the coulee cricket reared in the insectary at Pullman. It is evident that the crickets pass through six instars before they reach maturity. The instars of this cricket varied in time from six to twelve days with an average of nine and three-fourths days, but the average length of time for a great many others under observation was about eight days. This particular individual and many others reached maturity during the last week of April and the first few days of May. Owing to the writer's absence from May 2 to 21 observations were interrupted and it is impossible to state at what date the crickets began to mate. On account of another absence from May 24 to June 12 it is not possible to tell just when oviposition began, but by June 12 the insects were already depositing their eggs. Although the cricket under discussion died on July 1, as did many others about that time, still some lived well along into August—the last one, a female, dying August 15. Just how this longevity in the insectary compares with that under field conditions we cannot say, but Snodgrass (8, 1905) states that it is reported that by the middle of July all crickets are dead.

TABLE II.

A Comparison Between the Number of Crickets in the First and Second Instars in the Field at Stratford, March 16, 17, 18

Date	Time of Day	No. in first instar	No. in 2nd instar
March 16	2:15 P. M.	25	1
March 16	3:30 P. M.	27	1
March 16	3:40 P. M.	35	1
March 16	4:15 P. M.	20	1
March 16	4:25 P. M.	30	1
March 16	4:45 P. M.	20	1
		Total 157	Total 6
March 17	2:00 P. M.	20	10
March 17	2:15 P. M.	20	20
March 17	2:30 P. M.	14	4
March 17	2:45 P. M.	8	4
March 17	2:50 P. M.	16	20
March 17	3:00 P. M.	18	6
March 17	3:15 P. M.	14	4
March 17	3:20 P. M.	12	10
March 17	3:30 P. M.	14	20
March 17	4:00 P. M.	4	32
March 17	4:15 P. M.	5	30
March 17	4:25 P. M.	4	27
March 17	4:45 P. M.	5	33
		Total 154	Total 220
March 18	9:00 A. M.	3	55
March 18	9:30 A. M.	5	40
March 18	10:00 A. M.	2	50
March 18	11:20 A. M.	4	27
March 18	11:35 A. M.	2	42
March 18	1:00 P. M.	1	28
March 18	1:10 P. M.	2	30
March 18	1:20 P. M.	3	34
March 18	1:25 P. M.	1	30
March 18	1:45 P. M.	1	25
March 18	2:20 P. M.	1	28
		Total 25	Total 389

The foregoing table shows that for this particular region nearly all of the crickets molted the first time during a period of three days. On March 16 only a very few were found in the second instar, but on the next day more of them were in the second than in the first instar and on the third day only a very few remained in the first instar. This no doubt indicates also that these crickets in this particular spot had all hatched out during a couple of days about a week previously, irrespective of when oviposition had taken place the previous year. After this first molt, however, there did not seem to be this same simultaneity of molting on any particular day,

but each succeeding ecdysis became more irregular until there were soon several instars of crickets present at the same time.

TABLE III.

Comparative Number of Crickets in the Different Instars, March 20-23, 1916. (Crickets brought in from field March 20.)

Lot	March 20		March 21		March 22			March 23		
	First Instar..	Second Instar.	First Instar..	Second Instar.	First Instar..	Second Instar.	Third instar..	First Instar..	Second Instar.	Third instar..
A	15	60	3	72	3	70*	0	2	50	0
B	3	120	1	115	0	110	0	0	100	0
C	0	40	0	38	0	38	0	0	36	0
D	2	80	0	80	0	79	1	0	64	11
E	5	85**	4	75	2	70	0	0	65	0

*The difference between the total number of crickets at this date and that of the former dates represents the number of crickets killed and eaten by their comrades.

**Ten crickets removed after this count.

TABLE IV.

Comparative Number of Crickets in Different Instars April 21 to May 1, 1916

Lot	April 21st				April 24th				April 25th						May 1st			
Instar	4th		5th		4th		5th		4th		5th		6th		5th		6th	
Sex	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
F....	5	0	0	0	3	0	1	0	0	0	2	0	0	0	0	0	1	0
G....	2	2	0	0	0	0	0	2	0	1	0	1	0	0	0	1	0	0
H....	3	2	0	0	2	1	1	1	0	0	3	2	0	0	2	2	1	0
I....	0	0	3	0	0	0	3	0	1	0	3	0	2	0	0	0	3	0

TABLE V.

Relative Growth of Crickets in the Insectary, Out-door Cages and in the Field.

Place	Date	Number of specimens (female)	Instar
Insectary....	April 20..	.....Many........	Fifth and Sixth
Field........	April 21..	...... 10	Fourth
Field.......	April 21...	...... 3	Fifth
Out-door cages	April 25...	.....Many........	Fourth and Fifth
Insectary....	April 25, 26	.....Several.......	Seventh (adult)

The above table shows that the crickets reared in the insectary developed more rapidly than those in the field or than those in the out-door cages. While something might be

laid to the care and the abundant food supply given those in the insectary it is more reasonable to believe that the more rapid development was due to the constancy of the higher temperatures.

MATING.

Courting and Mating.

During courting and mating the male is, for the most part, the active and the female the silent partner. The male alone has wings, and, tho they are rudimentary, he chirrups or sings with them to attract a female. He is especially apt to sing on warm, bright mornings, but will do so to a certain extent in the afternoon. If the day is cool and cloudy the male does not sing; neither does he do so for about a day after he has fertilized a female. If a male is confined with a female he courts her somewhat after the following manner: At about eight or ten o'clock, if the morning is fairly warm and bright, he begins to chirrup to the female who does not seem to pay any attention to his advances, but as he continues to sing and side up to her, feeling antennae with her and trying to get beneath her, she gradually becomes less indifferent to his presence, yet shows almost no response to all his pleadings. She does not attempt to escape from him, but by gently but firmly pushing him away with her nearest foot, when he makes too ardent advances, she shows that she is not to be too easily won. Often she assumes a tantalizingly receptive attitude and the male attempts to connect, but after many trials—she remaining patiently still the while—he gives up and goes away. One pair was observed courting and attempting copulation for two and one-half hours before they finally separated without mating. In another case the pair had courted only a few minutes when the female advanced toward the male, walked over to him then stopped and waited while he caught hold of her with his hooked cerci. After a few seconds there were several throbbing pulsations of the male's abdomen, and the white, seminal sac appeared and was passed to the female. The female pulled away at once then, turning the male over and tore the mass from him. The actual process of copulation lasts from three to ten minutes, after which the female goes about with her ovipositor well up off the ground so that the sticky mass will not become covered with par-

ticles of dirt and other rubbish. After a few minutes she may reach beneath herself and eat away a portion of the seminal sac, or her male consort, or her other comrades, may eat away some of it, but the greater part, and perhaps under normal conditions, all of it is absorbed into the bursa copulatrix. After an hour or so the mass has entirely disappeared.

Time of Mating of *Peranabrus scabricollis* in Insectary.

Several of the crickets under observation became adults about April 25, but owing to the absence of the writer they were not observed until May 21, when several pairs were found mating. At what time mating began we cannot say, but from this time until August 3 some of the crickets were mating or remating almost daily. Copulation invariably took place between eight A. M. and noon. In no case were pairs seen copulating after noon. Mating is affected even more than molting by the temperature and weather conditions. Mating did not occur in any instance when the weather was cool or cloudy and never under a temperature of 66 degrees in the shade even though the crickets were in the sunshine.

TABLE VI.

Time of Day When Male Crickets Stridulate

Date	Hour when Chirruping	Hour when Not Chirruping	Weather
May 21	1:00 P. M.		
June 22	8:00 A. M.		
June 22	9:30 A. M.		
June 30		5:30 A. M.	Cool, cloudy.
June 30	9:00 A. M.		Sun shining.
July 1	8:30 A. M.		Cloudy, 68°.
July 2		9:00 A. M.	Cool, 63°.
July 4	9:00 A. M.		Bright, warm.
July 4	1:00 P. M.		Hot, 90°.
July 5	3:00 P. M.		Hot.
July 6	1:00 P. M.		Hot.
July 7	4:00 P. M.		Hot.
July 13	9:00 A. M.		Bright, 65°.
July 14		5:30 A. M.	Cool, cloudy.
July 14	9:00 A. M.		Bright, warm.
July 14	9:15 A. M.		Warm, 70°.
July 15		3:30 A. M.	Breaking daylight, cool
July 15		4:00 A. M.	Just daylight, cool.
July 15	8:00 A. M.		Bright, 79°.
July 16		7:00 A. M.	Bright, cool.
July 16		7:00 P. M.	In evening shadow.
July 17		8:00 A. M.	Cool, raining.
Aug. 8		8:00 to 12 A.M.	Cool, raining, 60°.
Aug. 10		8:30 to 12 A.M.	Cool, raining, 67°.

The male crickets chirrup or sing to the females at almost any time between the hours of eight A. M. and four P. M. Whether they sing at all or not depends upon the temperature and the condition of the weather. They do not sing if the temperature is below 65 degrees in the shade but will do so even at a temperature near 100 degrees. If the day is cool and cloudy they do not sing; and if the weather in general is warm but a cloud passes overhead they cease to chirrup until the cloud has passed. Males do not chirrup for about twenty-four hours after copulation.

TABLE VII.

Polygamy and Polyandry in *Peranabrus scabricollis*

Remating of pairs	Remating of males	Remating of females
No. 1, June 17, 22, 27; July 9, 20; Aug. 5.	No. 8, June 13; July 5, 9, 10.	No. 12, July 5, 9.
No. 2, June 21; July 8, 9, 13.	No. 9, June 14, 15.	No. 13, June 17, 22, 27; July 9, 13, 22; Aug. 3.
No. 3, July 14, 15	No. 10, June 21; July 9.	No. 14, June 21; July 9, 13.
No. 4, July 14, 15, 21.	No. 11, June 18, 21; July 8, 9, 13, 25; Aug. 2, 5.	No. 15, July 5, 14, 21, 27; Aug. 1, 3, 8.
No. 5, June 26; July 4, 16.		
No. 6, June 17, 22.		
No. 7, June 17, 22.		

The above table is not a complete record of the matings of any of the specimens, for mating had been going on many days before these observations were made and no doubt many took place between these dates, but the facts presented show that pairs do remate a number of times, that a given male will fertilize a number of females, and that a female will receive many different males. Just what the normal conditions are in this respect we cannot say, and just what are the limitations in the capacity of males and of females our observations have not shown.

TABLE VIII.

Comparative Number of the Two Sexes.

Series	Date	No. Females	No. of Males
Collected from field	May 1, 1914	29	36
Collected from field	May 18, 1914	27	11
Confined in Insectary	Apr. 20, 1916	28	29
Confined in Insectary	Aug. 1, 1916	3	8
Confined in Insectary	Aug. 10, 1916	2	2
Confined in Insectary	Aug. 12, 1916	1	0

From the foregoing figures it would seem that in the field up until the middle of May at least the two sexes may be about equally divided in numbers. According to Snodgrass (8, 1905) toward the end of the oviposition season the females die off and are killed by the males until none but males are left.

The Seminal Sac.

In the process of copulation the male passes to the female a large, conspicuous, white mass which the female receives in her bursa copulatrix, but which remains for an hour or more outside just beneath the base of her ovipositor. Snodgrass (8, 1905) regarded this mass as a plug, the function of which was to close the bursa copulatrix of the female. Gillette and Johnson (14) considered the analagous mass in *Anabrus simplex* as the seminal sac and such the writer has found it to be. On July 13 at nine-thirty A. M. a mass was removed from a female which had been fertilized within the preceding half hour. The whole mass was pulled away readily and remained as one jelly-like body. This mass was then washed in water and then in alcohol; a needle was then inserted at the front or bilobed end and some of the inside material removed to a slide. With an oil immersion objective the sperms could be readily distinguished actively gyrating about in the water of the mount.

Length of Time the Seminal Sac Remains Attached to Female.

The length of time required for the female to absorb the seminal sac passed to her by the male in coitu varies from forty-five minutes to four and one-half hours, but on the average it takes from one to two hours. Part of the seminal sac is absorbed by the female, the contents of which fertilize her ova, but a part of many of the masses is eaten by the female or, as sometimes happens, by the male or other female companions. As pointed out by Snodgrass (8, 1905), and Gillette and Johnson (14) (for *Anabrus simplex*) the seminal sac is never seen in the afternoon except in the first hour.

OVIPOSITION.

On May 20 and 21, 1914, which was near the beginning of the oviposition period, ten female crickets were dissected and eggs found as follows: 35, 35, 38, 42, 45, 45, 46, 52, 58,

59. It is possible that some of these females had already deposited some of their eggs. A very few eggs, found in some of the crickets' ovaries, were so small that they were not counted. These figures give at least an approximation to the number of eggs contained by each female.

In one experiment in 1916 one female deposited 40 eggs. In another cage two females deposited 150 eggs.

Oviposition may take place at almost any time of day but it is more largely confined to the afternoon when the females are frequently seen in the characteristic egg-laying attitude.

Time, Manner and Place of Hatching of Eggs.

As already pointed out in the general discussion of this subject, the eggs are deposited in the more or less well-defined scabland areas, yet within these localities the eggs are found only in particular places, mainly about the base of tiny grass stools, where the females were able to hold onto the grass-blade while ovipositing. Within an area of a couple of square inches, in the midst of such grass stools, many of the eggs can be readily found by digging about one-fourth of an inch below the surface of the ground. Although the eggs are placed singly, many times several are found standing vertically side by side with sides touching. The eggs are also commonly found inserted between the bases of the grass stems (Fig. 34, A).

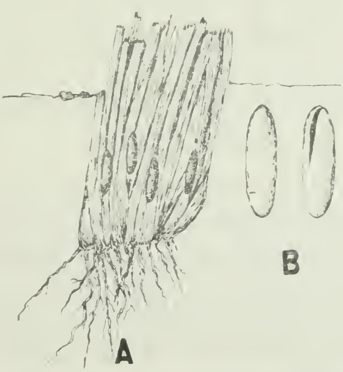

Fig. 34. A. Eggs, natural size, as they occur in the midst of the stools of "sheep grass." B. The initial splitting of the shell when hatching (X2½).

On a southern exposure near Stratford the first eggs hatched in the spring of 1916 about March 7, 8 and 9. At this time there was a period of three days of warm weather when the temperature was higher than at any period since the preceding October. After that date the weather turned cooler and hatching continued for about a week or more especially upon the higher land. The farmers in the Stratford district reported that two years ago the young crickets were seen during the last of February.

When the egg is ready to hatch it splits over one end and down the side about half way (Fig. 34, B) and the baby cricket pushes out its head. At first the antennae and legs are pressed close up against the cricket's body, but as it slowly and gradually pushes itself out of the egg shell the limbs come free, much as in the molting process which occurs later on in the cricket's life, and the new baby cricket crawls up out of its shell on to the stubs of grass and dries itself in the sun. When the young cricket is first hatched it is pink in color, similar to what it is later just after casting its skin, but after a few hours it has gained its regular dark brownish to black color. Within twelve hours at least after hatching the young cricket is jumping and crawling actively about, but apparently it does not eat for a day or more. When first hatched the cricket is 4.5 mm. long.

MISCELLANEOUS

Calosoma zimmermanni Leconte, a Predaceous Enemy of the Coulee Cricket.

On March 17, 1916, a small cricket was placed near a specimen of the Carabid beetle, *Calosoma zimmermanni*, an insect about three-fourths of an inch in length, when the cricket was immediately pounced upon and devoured in a very few minutes. On March 20, some second instar crickets were placed in a small glass dish with two of the beetles, which jumped fiercely upon them, grabbing them just back of the pronotum, and ate them all, except the legs, in a few moments. On March 25, after fasting for five days, the two beetles were given a third instar cricket. A rough and tumble fight ensued for the possession of the prey, but after a few minutes

they each got a part and went and ate it in opposite sides of the cage. When one of the beetles had finished its part of the first cricket a second was given and was soon captured, but this time the captor was successful in getting a hold only on the face of the cricket and therefore had some little difficulty in killing it. Within five minutes this second cricket was completely devoured except the legs. After an hour's interval, the beetle, which had already eaten more than its share of the two other crickets, was given six third instar crickets. Inside of 15 minutes one cricket had been eaten, and during each 15 minute interval for the next hour the crickets disappeared one by one. After the beetle had killed and eaten five crickets it killed and partly ate two more, but by that time it was obliged to quit. The next morning the few fragments left over from the previous day's orgy were devoured. This beetle is thus a more or less important natural enemy of the coulee cricket since it and other species of Carabidae are rather common in the Upper Sonoran Zone where the cricket is found.

Poison Bait Experiments on Young Crickets in the Insectary.

TABLE IX.

Results of Poison-Bait Experiments on Second Instar Crickets in Insectary—First Experiment March 20-24, 1916

Arsenical	Strength........	No. crickets used...	No. killed first day.	No. killed 2nd day..	No. killed 3rd day..	Total dead, 3rd day.
Sodium arsenate and horse manure	1-25	10	0	6	4	10
Sodium arsenate and horse manure	1-25	10	4	5	1	10
Sodium arsenate and horse manure	1-50	10	1	1	8	10
Sodium arsenate and horse manure	1-65	10	3	5	2	10
Sodium arsenate and horse manure	1-65	10	0	6	4	10
Sodium arsenate and horse manure	1-100	10	2	4	4	10
Check (no food)..................		10	1	1	3	5*
Check (manure)		10	1	2	2	5*

*Killed by comrades.

TABLE X.
Second Experiment, March 23-27, 1916

Arsenical	Strength	No. crickets used		Killed first day	Killed 2nd day	Killed 3rd day	Killed 4th day	Total dead, 4th day
		Hungry	Fed					
Sodium arsenate and horse manure	1-100	10		3	5[1]	1	1	10
Sodium arsenate and horse manure	1-100		10	3	1[2]	3	3	10
Sodium arsenate and horse manure	1-200	10		3	6[3]	0	1	10
Sodium arsenate and horse manure	1-200		10	0	0[4]	4	4	8
Paris green	1-100	10		1	5	2	2	10
Paris green	1-100		10	0	2[5]	3	2	7
Arsenate lead	1-100	10		0	2	4	3	9
Arsenate lead	1-100		10	0	1[6]	2	3	6
Arsenite of zinc	1-100	5		1	1	2	1	5
Arsenite of zinc	1-100		10	2	1	1	5	9
Check (manure)		5		1	2[7]	0	0	3
Check (manure)			10	1	2[8]	0	2	5
Check (no food)		10		1	0[9]	5	4	10
Check (no food)			10	0	0[0]	2	6	8

[1]1 molted; [2]1 molted; [3]1 molted; [4]8 molted; [5]7 molted; [6]5 molted; [7]1 molted; [8]5 molted; [9]2 molted; [0]4 molted.

The two columns in the second experiment designated as "hungry" and "fed" mean that the crickets used were either some that had been fed right along previous to the experiment or else they were some that had been starved for several days.

In the fore-going laboratory experiments (Tables IX and X) 100 crickets, toward the end of their second instar, were given fresh horse manure mixed with solutions of sodium arsenate, so as to represent concentrations varying from 1 to 25 to 1 to 100. By the end of the fourth day all these crickets were dead. Of 55 crickets reserved for checks 19 were alive at the same time, most of the others having been killed and partly devoured by their comrades. Eighteen crickets out of 20 fed with a 1-200 arsenate-manure mixture succumed in four days. Repetition of this experiment with 1% mixtures of lead arsenate, Paris green and zinc arsenite showed mortalities of 75, 85 and 93% respectively, at the conclusion of four days' feeding. In many cases the crickets molted during the test, which may explain why they were not poisoned, for the day before and the day following molting young crickets refuse food.

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SUMMARY.

The coulee cricket occurs in restricted localities in Montana and Washington and in the latter state has sporadically appeared in immense migratory hordes which devastate whatever vegetation grows in their pathway.

The insect breeds in non-arable areas characterized by the presence of the scabland sage brush, *Artemisia rigida*, among the fallen leaves of which the newly hatched crickets secure protection in early spring.

The life cycle comprises seven stages: during the first four the insects feed in the breeding grounds; at the fifth instar the crickets begin moving in bands to spread over miles of country.

Mating is indiscriminate, the crickets are both polygamous and polyandrous. The consummation of copulation is effected by the female tearing from the male genitalia a large white lobose sperm sac, which is awkwardly carried about for approximately an hour.

Eggs are laid singly, usually at the base of grass stems, each female averaging about fifty. Eggs are deposited during the migrations whenever the insects come to a favorable location.

The coulee cricket is practically omnivorous, feeding on desert plants, dung and dead animals. If other food is available it will not eat peas, but when pressed for food it strips even the bitter sage brush. It is markedly cannibalistic and attacks and devours weakened individuals throughout its life cycle.

Sparaison pilosum has been reared as an egg parasite, and *Calosoma zimmermanni*, *Cyrtopogon maculosis* and species of ants have been observed as predatory on small crickets.

In the way of control young crickets are more easily reached and more easily killed than after they have spread from the restricted breeding grounds, and are vulnerable to the following treatments: Spraying with 5 to 10% emulsified kerosene destroys newly hatched crickets but not old ones. Fresh horse manure containing 2% of an arsenical is an efficient poisoned bait. Burning with straw or with an insecticidal blast torch is practical.

To check migratory crickets vertical-walled ditches containing deeper pitfalls are dug across their path. The insects massing in the pits quickly smother out each other's lives. Fencing of 1 by 8 inch boards joined end to end on edge and furnished with frequent pitfalls is sometimes employed in place of ditching.

The crickets congregating about trenches or fences form valuable food material for hogs or fowl. Those dying in the pits decompose with much stench unless scattered out to dry quickly.

The coulee cricket is a menace to ranches located miles from the breeding grounds. So far it is restricted to a relatively small area near the center of the Big Bend district, but as there are thousands of square miles of similar country contiguous to the cricket area it is impossible to foretell that the species will not spread. As the region is thinly populated the suppression of the species should devolve on the community and not on the isolated ranchers first affected.

Fig. XXXV. Male of the coulee cricket. (After Snodgrass.)

Fig. XXXVI. Female of the coulee cricket. (After Snodgrass.)

Fig. XXXVII. Coulee cricket depositing eggs at base of "sheep grass." (After Snodgrass.)

STATE COLLEGE OF WASHINGTON

AGRICULTURAL EXPERIMENT STATION

PULLMAN, WASHINGTON.

ADAMS BRANCH EXPERIMENT STATION

First Annual Report

For the Year Ending June 30, 1916

BULLETIN NO. 138

February, 1917

All Bulletins of this Station sent free to citizens of the State on application to Director

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Ira D. Cardiff, Ph. D., Director .... Pullman
M. A. McCall, B. S., Superintendent .... Lind
M. B. Boissevain, Assistant in Farm Crops in charge of Waterville sub-station .... Waterville
Peter Jacquot, Assistant in Dry Farming .... Prosser
C. A. Weaver, Farm Foreman .... Lind

LETTER OF TRANSMITTAL

Lind, Washington, January 15, 1917.

Director Ira D. Cardiff,
Washington Experiment Station,
Pullman, Washington.

Dear Sir:

I have the honor to transmit herewith the first annual report of the Adams Branch Experiment Station for the fiscal year ending June 30, 1916.

Very respectfully,
M. A. M'CALL.
Superintendent.

Fig. I. Barn constructed on Adams Branch Experiment Station December, 1915, under supervision of Supt. M. A. McCall. Plans furnished by I. D. Charlton, Professor of Agricultural Engineering, State College. Size of barn, 50x38. Total cost of barn, completed and painted, $1443.

FIRST ANNUAL REPORT
of the
Adams Branch Experiment Station

Establishment. The Adams Branch Experiment Station, located at Lind, Adams County, was organized as a branch station of the Washington Agricultural Experiment Station during the fiscal year ending June 30, 1916, for the purpose of conducting investigations in dry farming agriculture.

Location. The farm is located three miles northeast of the town of Lind, is one-half mile from the main line of the Northern Pacific Railway, and three miles from the Chicago, Milwaukee and St. Paul Railroad. The legal description of the tract is the S$\frac{1}{2}$ of Section 32, Township 18 North, Range 34 East of the Willamette Meridian. This is practically the geographic center of Adams County and the land is typical of Central Washington agricultural land.

Coöperation. The farm is the property of Adams County, and is leased to the Washington Agricultural Experiment Station for a long term of years, provided it continues to be used for experimental purposes.

Some time after the establishment of the station a coöperative agreement with the Office of Cereal Investigations, Bureau of Plant Industry, United State Department of Agriculture, was made providing for coöperation in cereal investigations.

The courtesy of the Committee in charge of the Adams County Demonstration Farm in loaning equipment aided very materially in the establishment of the Station. The Chicago, Milwaukee and St. Paul Railroad also aided thru a liberal cash contribution.

THE AREA SERVED BY THE ADAMS BRANCH EXPERIMENT STATION

Agricultural History of the Area. The development of the territory intended to be served by the Adams Branch

Fig. II. Foreman's cottage constructed on Adams Branch Experiment Station, Ocober, 1915, under supervision of Supt. M. A. McCall, plans and specifications furnished by Professor Rudolph Weaver, Department of Architecture, State College. The cottage contains five rooms, bath room, and small hallway. Bath frurnished with tub, lavatory and wash bowl. Kitchen with sink, hot water tank, built-in cupboards. Cost complete with plumbing, water and sewer connections, $900.00.

Experiment Station is comparatively recent. Settlement by stockmen began in the early 70's and the more favored sections were settled and wheat growing began during the 80's, but not until after the bumper wheat crop of 1897 did a farming population occupy the greater part of the country. Nineteen hundred one and 1902 saw the greatest influx of settlers. For several years the country prospered, but the introduction and spread of the Russian Thistle, (*Salsola tragus*), and the Tumbling mustard, (*Sisymbrium altissimum*), together with the development of the soil drift problem, led

Fig.III. A typical drifting "blow" soil, Western Adams County.

to a period of more or less reverse. Considerable areas were deserted and became a wilderness of mustard, and criticism of the country and its possibilities followed. Better methods of tillage and weed control, and better crops and prices have is again settled and profitably farmed. There are many problems, however, awaiting solution and much remains to be accomplished.

Extent and Importance. The dry farming area of Central Washington embraced in the counties of Adams, Benton,

Fig. V. Gas combine harvester owned by V. S. Phillips, Lind, Wash., A

raphed by J. Elmer & Co., Krupp, Washington.

tended to restore confidence and much of the deserted area Douglas, Franklin, Grant and Lincoln totals 7,422,720 acres or slightly more than one-sixth the total area of the state exclusive of water bodies. According to the census report of 1910 the total farm lands of the state aggregate 11,712,-235 acres of which 6,373,311 acres are classified as improved farm lands. In the area in question the same report places darm lands as follows:

County	Area in Acres	Acres in Farms	Acres of Improved Lands
Adams	1,223,680	979,455	747,778
Benton	1,069,440	260,044	186,397
Douglas	1,143,680	711,831	472,625
Franklin	771,840	387,832	273,241
Grant	1,740,800	647,999	444,622
Lincoln	1,473,280	1,209,910	799,380
	7,422,720	4,197,071	2,924,043

Using the above data as a basis for comparison we find that 45.8% of the improved farm lands of the state are em-

Fig. IV. Dry land alfalfa. Jos. Clay, Quincy, Grant County, Rows three feet apart. From Fig. III., Gen. Bul. 128, Wash. Exp. Sta.

braced within these six counties. Reducing the total acreage of improved farm lands of these counties to a round number of 2,000,000 acres, to account for land now irrigated or feasible of irrigation in the comparatively near future, we still have 31.3% of all the improved farm lands of the state which will probably always be farmed by dry farming methods. In addition to the lands within the six counties above listed

there are others in portions of Walla Walla, Whitman, Spokane, Ferry, Okanogan, Columbia, Yakima, Garfield, Asotin, Klickitat and other counties which make it reasonable to say that at least 40% of the improved farm lands of the state can only be brot under profitable cultivation by dry farming methods.

It is true that problems are not equally difficult in all parts of the area, but in a considerable part of it they are sufficiently acute to make their solution of great benefit to the state in the increase of values and in possibilities for supporting a larger population. For this reason there is perhaps no investment in experimental appropriation offering more in the way of direct return to the state than that for dry farming investigations in this section.

Topography. Topographically the area is a rolling plateau more or less cut by dry coulees, some few carrying small streams during all or part of the year. General drainage is south and west toward the Columbia, Snake and Yakima Rivers. Elevation varies with a gradual increase toward the north and east. Elevation is a general indication of probable rainfall and soil type in this area, the higher elevations usually having more rainfall and a heavier soil type.

	*Elevation	*Rainfall
Pasco, Franklin County	367 ft.	6 46 in.
Hatton, Adams County	1,100 ft.	9.13 ft.
Lind, Adams County	1,600 ft.	12.02 ft.
Wilbur, Lincoln County	2,203 ft.	13.67 in.

Climate. The climate as a whole is semi-arid, varying from nearly sub-humid on higher elevations of the north and east to arid in lower elevations of the south and west. Most of the precipation comes as rain or snow in fall, winter and spring, the summers being as a rule dry. May and June rainfall have a very important bearing on crop yields, altho good crops have been grown without rain at this time of the year. The above table gives rainfall for representative stations in the area, and also indicates the general relationship between altitude and precipitation.

Temperatures are not extreme either for summer or winter. Nights during the growing season are on the average cool, the total heat units for the season being compara-

*Taken from "Summary of the Climatological Data for the United States by Sections." Reprint of Section 20, Eastern Wash., U. S. W. B., 1915.

tively low, altho there is usually a certain amount of hot weather during the dry season. Winds during spring and fall are as a rule frequent and often of high velocity, but reliable data on the winds is lacking. Local variations in climatic conditions occur and observations at an increased number of stations are desirable to locate these differences.

Soils. The soils of this region are basaltic in origin, chiefly deposited by wind agencies. Their physical nature is aptly described by the local designation, "volcanic ash" soils. Depth, uniformity and great fertility are characteristic of these soils, the chief difficulties and problems being due to their physical condition. Most of the soils, especially in the drier localities are deficient in clay for binding qualities, and this, together with the removal of organic matter thru

Fig. VI. Field peas in rows. F. A. Hauter, Warden, Grant County. These peas were seeded in February and harvested June 1st. This shows the crop on June 25th. They yielded more than a ton per acre of cured pea hay. From Fig. V., Gen. Bul. 128, Wash. Exp. Sta.

rapid oxidation under the clean cultivation of the summerfallow system, has developed a serious problem in the drifting of these soils by the wind. Not all soils of the region are so affected, those particularly of the higher elevations being heavier in type. The farm practice of burning weeds and stubble may also have aggravated the condition in many instances.

Cropping System. Practically the only cropping system followed is that of alternate years of summerfallow and crop. The ground is plowed in early spring, and given such tillage

as is necessary to keep it mulched and free from weeds. In the northern part of the area spring wheat is most extensively grown, while the southern portion seems best adapted to fall seeding. Winter wheat when grown successfully, however, on the average, gives better yields. The advent of the tumbling mustard has led many farmers to abandon fall seeding unless fall rains come early enough to start the weed seed and permit of cultivation before seeding. Wheat and rye are practically the only crops grown, rye being grown in extreme cases where soils drift badly, or on light shallow soils for pasture.

INVESTIGATIONS INAUGURATED

The farm having been a tenant farm required one year of preliminary tillage to prepare it for investigational work. The season of 1916 was devoted to this preparation and to laying out the farm for experimental purposes. Investigations will be initiated during the fall of 1916 as follows:

Project No. 1. **Cereal Investigations:**
- (A) Variety trials
- (B) Rate, date and depth of seeding trials
- (C) Cereal breeding
- (D) Cereal disease investigations.

Project No. 2, **Forage Investigations:**
- (A) Variety and management trials
- (B) Forage crop breeding
- (C) Silage and silage crop trials.

Project No. 3. **Tillage Investigations:**
- (A) Summerfallow methods
- (B) Spring cultivation of grain trials

Project No. 4. **Permanent Fertility Investigations:**
- (A) Fertilizer trials
- (B) Maintenance of organic matter
- (C) Rotations.

Project No. 5. **Tree Investigations and Distribution:**
- (A) Variety and management trials
- (B) Distribution.

Under this project some 20,000 trees have already been distributed in Adams, Benton, Franklin, Grant, Douglas, Lincoln and Walla Walla counties. These have been used for

Fig. VII. Winter rye grown for pasture, western Adams County. Rye has proved one of the most valuable forage crops of the drier districts. From Fig. VII., Gen. Bul. 128, Wash. Exp. Sta.

Fig. VIII. Cattle on rye pasture. W. W. Haile, Cunningham. Mr. Haile is adding to his herd and seeding more rye to pasture. From Fig. IX., Gen. Bul. 128, Wash. Exp. Sta.

windbreaks and for plantings around building sites, the latter being most successful. Too close planting is the chief cause of failure in the windbreaks. The varieties most successful

are the Black Locust for general plantings, the Russian Olive for shrubs, and the poplars in a minor way.

Project No. 6. **Post Treating Trials:**

(A) Creosote and zinc chloride treatment

(B) Trial of various woods for fence posts

Project No. 7. **Coöperative Experiments in Benton County:**

(A) Coöperative trials in the Horse Heaven

Under this project work has been carried on for the past two years with an experienced and successful dry land farmer in immediate charge of the work. This dry land specialist has visited practically every dry land farm in the county, and while results are difficult to measure, there is

Fig IX. 75 H. P. Caterpillar, two-speed low, operated by L. O. Reeder, Hatton, Washington, pulling fifteen fourteen-inch Oliver plows. Plowing strip 17½ feet wide, making 49 acres per day. Power farming by means of tractors, combines, etc., has proved in many cases the more economic method in Central Washington.

no doubt that a very great improvement in farm practices is noticeable as a result of this work.

Project No. 8. **Meterological Observations:**

(A) Establishment of rain gauge stations

Under this project eight rain gauge stations have been established and data collected. Plans are under way for the

extension of this work to cover practically all conditions of the central Washington dry farming territory not already covered by stations of the U. S. Weather Bureau.

Project No. 9. **Livestock:**

(A) The encouragement of livestock production.

Under this project several head of pure bred livestock have been placed with farmers in various parts of the dry country for the use of the community. A dairy strain Shorthorn bull has been placed in Franklin county. Pure bred Duroc Jersey and Tamworth hogs have been placed in Adams and Benton Counties as a community foundation for better stock.

Project No. 10. **Plant Introduction.**

(A) The introduction and trial of promising foreign plants.

It is believed that there are a large number of economic plants growing in other parts of the world which can be successfully grown in the drier districts of Washington. The Station, therefore, is planning to test out as many of these plants as can be obained thru coöperation with the Office of Foreign Seed and Plant Introduction, U. S. Department of Agriculture. A number of fruit and ornamental trees and shrubs have already been started and a dozen or so new varieties of grain and forage crops have been placed under test. The number of plants so tested will be increased from year to year and it is hoped that some varieties, especially suited to Central Washington, will be obtained.

In addition to the projects outlined others will be added as equipment and funds permit.

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF BOTANY

Plant Physiology

Microchemical Studies in the Progressive Development of the Wheat Plant

By

SOPHIA H. ECKERSON

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Microchemical Studies in the Progressive Development of the Wheat Plant

By

SOPHIA H. ECKERSON*

SUMMARY

Inorganic materials are high in the young plant.

The largest amount of potassium nitrate was found, chiefly in the root and stem, just before formation of the spike. From that time on, it decreases gradually.

Free magnesium quickly falls to a minimum during formation of the aleurone.

Free phosphate rapidly rises to a maximum during development of the sporogenous tissue; after development of the sex cells it falls to a minimum.

Asparagine seems to be a very important nutritive substance for growth. It was found together with fructose in all young growing regions.

Pectic substances on the stigma are especially important in reducing the rate of water absorption by pollen grains.

From fertilization of the egg to the mature grain a stream of nutrient materials for the growing embryo comes to the endosperm from the leaves and glumes: fructose and glucose, asparagine, arginine, histidine and leucine. Any excess of sugar condenses at once into starch. The excess asparagine and amino-acids remain as such in the endosperm cells until desiccation of the grain.

The nitrogen compounds, aside from aleurone and protoplasm, in the endosperm just before ripening of the grain are: much asparagine, considerable arginine, histidine, and some leucine. No glutamine was found.

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*Thru the courtesy of the Department of Botany of the University of Chicago, the services of Dr. Sophia H. Eckerson, Instructor in Plant Physiology in that institution, were loaned to the Washington Experiment Station for five months for the purpose of conducting this work. The Washington Station acknowledges with sincere appreciation the assistance thus rendered by the University of Chicago.

On desiccation of the grain protein appears in the storage cells; the amino-acids and most of the asparagine disappear. The protein has the physical characters of gluten.

Formation of the storage protein in wheat seems to be a condensation process, and it takes place on desiccation of the wheat kernel.

INTRODUCTION

The work reported here is a part of the organized study of wheat on which the Station is engaged.

The chemical and morphological development of wheat was followed from the primordia of the flower to the mature grain. Jensen has studied the morphological development; his results will be described in another bulletin of this Station. This paper gives the progressive chemical changes which take place during the development and ripening of the grain. Microchemical methods were used on the living tissue; where possible the work has been checked up with Olson's results by macrochemical methods.

METHOD

Microchemistry.—In the microchemical study several different tests were made for each substance. First, color reactions for orientation; second, specific chemical reactions and solubility tests. This is necessary since in the plant cell we are not dealing with a single substance, as a chemically pure substance in a test tube, but with a mass of substances. If positive results are obtained with two or more different reactions, one can be reasonably certain that the substance tested for is present. On the other hand, it must be noted that negative results with any single test do not necessarily indicate an absence of that substance; the reaction, or the appearance of it, may be prevented by the state in which the substance is present or by some other substance present in the tissue. A list of the tests made for each substance is given at the end of the bulletin (p. 13). Details of the reactions can be found in Tunmann's microchemistry (13).

Varieties of wheat studied.—A preliminary study was made of Marquis, Hybrid 143, and Bluestem grown in the Station greenhouse. Then, the course of development was followed in Little Club, grown in the experimental plots on the Station Farm, both fall sown and spring sown; and certain important stages in the development, between fertilization and desiccation of the grain, were studied in Red Russian, Turkey Red, Hybrid 526, and others.

Routine of work.—The wheat was brought from the field to the Station laboratory each morning, put in water and placed in a south window. Sections were made, either with a freezing microtome or free-hand. Tests for the various substances were made in the order of their plasticity and ease of translocation: first fructose and glucose, then amino-acids, nitrates, phosphates, etc.

Comparative tests were made on wheat gathered at different periods of the day. In the very early stages, during development of the flower, there was no distinguishable difference; but for a short period, from fertilization to the development of the endosperm, there was a distinct difference. This was due, in part, to the different amounts of water in the head. It will be described later.

INVESTIGATION

The progressive chemical changes during the development of the wheat grain are correlated with the morphological changes; each definite period of the morphological development is characterized by some chemical difference. The progression of these chemical changes was alike in all the varieties tested and in both winter wheat and spring wheat. One general statement may be made before giving the course of development. Throughout the growth of the plant the young parenchyma cells (the meristem) of any growing region contain a greater amount of fructose and of asparagine than the adjacent parenchyma cells. No glucose and no other non-protein nitrogen compounds could be detected, although these were always found in the vascular tissue which supplies the growing parts. This point will be brought up again in the discussion.

CHEMICAL CHANGES DURING DEVELOPMENT

Young Spike

A continuous stream of sugar and amino-acids moves from the leaves to the culm and thence into the young spike. In the vascular elements of the culm there are present fructose and glucose; some arginine and histidine, considerable asparagine; and a large amount of potassium nitrate. Apparently all of these substances are being moved into the spike, but in the meristem of the growing points along the spike there is only fructose, asparagine, and a little potassium nitrate. Potassium nitrate is present in small amounts in all parenchyma cells during the growth of the plant. The cortical cells of the culm, and espe-

cially the vascular plate at the nodes, contain much magnesium oxalate; this is present also in the spike in smaller quantities. There is some calcium in all parts of the culm and spike, chiefly, or wholly, in the form of calcium pectate.

Between the spike and its enveloping leaves is a layer of mucilaginous pectic compounds; there is a small amount of glucose in this pectic mass, also some calcium. This mass of pectic substances holds the moisture and thus keeps the amount of moisture in the young spike nearly constant. This offers an explanation of the fact that no chemical difference was found in the young spike at different periods of the day.

We may briefly tabulate the outstanding facts of this period of development as follows:

no phosphate (or merely trace),
maximum potassium nitrate,
much magnesium oxalate,
much pectin mucilage.

By maximum potassium nitrate is meant that in proportion to the extent of tissues involved, there is more potassium nitrate in the plant at this time than at any later stage of its development.

Primorida of the flower

As found in all actively growing tissue during development of the spike, the cells of the primordia of the flower (excepting the epidermal cells) contain much fructose and asparagine. The primordia of the glumes and of the stamens and pistils are alike chemically; but later, when the sporogenous tissue is developing phosphate begins to enter the stamens and pistil in larger quantities. More is found in the sporogenous tissue than in any other part. At this time the magnesium oxalate crystals in the spike disappear and magnesium appears in the sporogenous cells. Since magnesium and phosphate are in the same cell, it is probable that they are in the form of magnesium phosphate*. A trace of a soluble oxalate is present—probably potassium oxalate. Phosphate continues to move into the sporogenous tissue until the pollen grains and the egg are formed. Potassium nitrate is present in small amounts; it is gradually decreasing in the vascular tissue of the culm. There is still considerable magnesium oxalate in the culm, especially near the base of the spike.

*There is a decreasing gradient to the sporogenous tissue, but some cells a little aside from the direct route frequently contain more of these substances for a few hours than the adjoining conductive tissue.

The most characteristic changes during this period are as follows:

Decreasing magnesium oxalate
Decreasing potassium nitrate
Increasing phosphate
Decreasing pectin around spike.

Pollen Grains

Young pollen grains, having one nucleus, contain phosphate, a trace of magnesium, some fructose, and much pectin. These pollen grains do not burst in water, probably because of the pectin which retards water-absorption. At this stage the spike is still in the "boot"; the anthers are still closed.

Older pollen grains, having a generative and a tube nucleus, contain less pectin, much glucose, and a trace of phosphate. There is also a trace of calcium, but always more magnesium than calcium. The pectin decreases and glucose increases for a time; suddenly starch appears. The turgor pressure increases tremendously; the pollen grains burst even in a molecular sucrose solution. The characteristic chemical changes are in three series:

1. One-celled pollen grain
   Maximum pectin
   Decreasing free phosphate.
2. Two-celled pollen grain
   Decreasing pectin
   Increasing glucose.
3. Mature pollen grain
   Disappearance of glucose
   Maximum starch.

Pericarp

The pericarp, particularly the part near the vascular tissues, contains much asparagine, also arginine, histidine, and leucine. The route of the amino-acids seems to be from the leaves and glumes-stem-pericarp-nucellus-embryo sac. There is usually more asparagine at the base of the grain than elsewhere in the stem, possibly because here the paths from the glumes and the leaves meet. The pericarp also contains much glucose, some fructose and starch.

The cells of the pericarp now begin to break down, and their contents apparently are moved into the embryo sac.

The outer integument breaks down at this time. There is much pectin between the pericarp and the inner integument and in the nucellus.

Embryo Sac

Four megaspores are formed by two successive divisions of

the megaspore mother cell. Phosphate moves into these cells through the nucellus. Like all newly formed cells of the spike, they contain much fructose and some asparagine. Gradually three of these megaspores lose their contents, while the functioning megaspore increases in size; it now contains more phosphate and more fructose than the surrounding tissue.

After the development of the functioning megaspore there is a short resting period of four or five days; suddenly the cell enlarges greatly and the megaspore nucleus begins to divide. Division continues until there are eight nuclei; thus the embryo sac is formed. Three of the nuclei, the antipodals, continue to divide and form a vigorous tissue-like mass at the base of the embryo sac. The egg enlarges somewhat; the organ is now ready for the entrance of the male nucleus. The characteristic feature of this period is: maximum phosphate.

Stigma

The plumose stigma contains much pectin and little glucose. Pectin together with a trace of glucose is exuded from the papillae of the stigma. At this time the pollen is shed; it falls on the mucilaginous pectin, germinates and sends its tube down through the stigma into the embryo sac,—there is pectin and a trace of glucose all the way. Evidently the pectin prevents a rapid absorption of water, so the pollen grains do not burst. If this is true, the pollen should germinate on any gel,—provided there are no injurious substances present. To test this a few experiments were tried.

Gels were made from currants and green apples by pressing out the juice and allowing it to evaporate until it stiffened; Wheat pollen was sown upon these gels. On the green apple gel the pollen grains did not burst but only a small percentage germinated. The currant gel, however, was a highly favorable medium.

Fertilization to Mature Grain

After fertilization, during free nuclear division of the endosperm nucleus, there is little movement of material into the embryo sac.

At the beginning of wall formation in the endosperm, the substances begin to come in rapidly; from this time on to the mature grain there is a steady and rapid growth of the embryo. At first the substances enter any part of the nucellus and pass through that into the embryo sac. The nucellar tissue, however,

soon breaks down; also the parenchyma tissue of the pericarp continues to break down and glucose and amino-acids pass into the embryo sac.

At this time the morphological development of the endosperm is complete. The outer membrane of the nucellus becomes suberized, forming a semi-permeable membrane. Now the stream of sugar and amino-acids passes from the base of the grain up through the raphe, enters the embryo sac at the chalazal region, and passes down through the endosperm cells to the embryo. Much asparagine is moving in; in grain gathered in the morning there is frequently a decreasing gradient all the way from the rachis to the embryo. But if the wheat stands in water in the laboratory for several hours there is more asparagine in the embryo than in the other parts.

Starch in endosperm.—Starch is formed in the endosperm cells soon after wall formation. It continues to increase in amount until desiccation begins, or as long as the leaves and glumes remain green and are making an excess of sugar.

Inorganic substances.—There is magnesium, phosphate and calcium in the aleurone layer; neither phosphate nor magnesium could be detected in the other endosperm cells.

Fat in endosperm.—There is a small amount of fat present.

Amino-acids in endosperm.—In the mature endosperm there is much asparagine, considerable arginine and histidine, and some leucine. It is possible that there are other amino-acids present,—those for which there are no distinctive microchemical tests. There are, however, distinctive tests for glutamine; neither glutamine nor glutamic acid was found. This is striking since hydrolysis of the wheat proteins by hydrochloric acid gives a large percentage of glutamic acid. This will be discussed later.

Protein Synthesis

In the full grown, still green wheat kernel (containing about 90% moisture) there is no storage protein in the endosperm. The aleurone layer and the layer of cells immediately below it contain more protoplasm than the other endosperm cells and, of course, give a protein reaction; this, however, is not storage protein.

No storage protein is formed in the endosperm until desiccation begins. Gluten appears at the same time as the storage protein.

In the earlier stages of the filling of the kernel the grain is devoid of gluten but following desiccation gluten appears in such

grain. From these microchemical tests it appears that the proteins gliadin and glutenin are formed when drying of the grain causes the amino-acids in the endosperm to condense into proteins. There can be no gluten, therefore, until desiccation of the wheat grain begins.

Grain which when brought into the laboratory gave no protein reaction, but contained much asparagine, arginine, histidine, and leucine, was dried for 12 hours. It then gave a strong protein reaction and contained gluten; but had much less asparagine than before. On further desiccation, arginine, histidine and leucine disappeared; there remained only a trace of asparagine.

Hydrolysis of protein.—The protein of mature dry wheat was hydrolyzed by means of papain, and the amino-acids identified. As before protein synthesis, much asparagine was found, also arginine, histidine and leucine. Proline, which was not found before synthesis, was now found in rather large quantity. But no glutamic acid was found.* A microchemical study of the amino-acids produced by normal enzyme hydrolysis of the proteins during germination would be of value.

DISCUSSION

Nitrates.—It has been shown by Adorjan (1) that the wheat plant takes up nitrates from the soil most strongly during the "stooling" period,—from 2-3 times the amount needed for the increase in dry weight. The intake decreases during the "shooting" period and after flowering the plant takes up scarcely any more. The findings in my series of tests agree exactly with those of Adorjan. At the time the young spike is beginning to form, all parts of the root and stem contain an excess of potassium nitrate. The amount decreases gradually and at the time of flowering there is little potassium nitrate in the conductive tissue. It must be remembered that there is always a trace of potassium nitrate in the protoplasm of all the cells.

Phosphates.—Maximum free phosphate was found in the stem and in all parts of the spike during development of the sporogenous tissue. After development of the aleurone in the endosperm, none was found. This, again, agrees with Adorjan. He found that the greatest absorption of phosphate is during the "shooting" period, and that after flowering no more is taken in. It appears, therefore, that the greatest absorption of phosphates is at the time they are being assimilated most strongly, while ni-

*Mr. Geo. Olson, Station Chemist, obtained some pure glutamic acid for the writer, so it was possible to check up the reactions.

trates are absorbed in large quantity by the young plant and are assimilated much later in the development. Phosphates are used in the formation of phospho-proteins, phospho-lipines, etc.; in the wheat plant they are assimilated in larger amounts during development of the sex organs than at any other time. Also the phosphorus seems to be built up into organic substances at the place where they are being used. Probably this is true thruout the development of the plant, for Iwanoff (6), following the course of phosphate in many plants, finds that it tends to accumulate in the young, still undeveloped parts; he concludes that it is assimilated in young leaves, probably in meristem, and in seeds,—in endosperm if present, or in the embryo. He adds that the disappearance of free phosphate in seeds takes place long before their drying out.

Calcium, magnesium.—No variations in the amount of calcium were observed. There is never much more than a trace of free calcium; it is chiefly in the form of calcium pectate.

Magnesium probably is absorbed in relatively large amounts during the early development of the plant. Just before spike formation there is considerable present as magnesium oxalate; later, when phosphate begins to appear in greater quantity, the magnesium oxalate breaks down,—probably magnesium phosphate is formed. During early development of the grain, especially of the aleurone, there is much more magnesium than calcium present. It is known that the mature wheat kernel contains 2-3 times as much magnesium as calcium. Chemical analyses [Wehmer (14)] show:

Percentage of ash	
MgO	CaO
10-16	2-5

According to Willstätter (15) this ratio is true for the grains of all cereals.

Pectic substances.—The exact chemical nature of the different pectic substances is not known, but they are easily recognizable by the differences in their physical characteristics. They go over easily from one form to another. The importance of these substances in relation to water absorption and water loss by plant tissue is coming to be more and more recognized. They themselves absorb water but do not allow it to pass through readily; they, therefore, retard water loss or reduce the rate of absorption, depending on their position in the plant tissues. Thus the pectic substances surrounding the young spike retard loss of water by the delicate tissue, and so prevent their drying out by evaporation. Again, the mucilaginous pectic substances on the

stigma form a good medium for germination of the pollen grains; since they decrease the rate of water absorption, the pollen germinates without bursting.

Gelatinous substances have been found effective media for germination of pollen which bursts in sugar solution. Kraus (7) finds a ½-2% gelatine solution effective for germination of some apple pollen. Martin (8) germinated clover pollen on pieces of pig's bladder. Possibly in both these cases it will be found that the plant effects the necessary low rate of water absorption, by pectic substances on the stigma.

Starch in endosperm.—Brenchley (2, 3) found that starch first appeared on the tenth day after endosperm formation. In the Pullman wheat, starch was found immediately after wall formation, and even before, in some cases. The actual time of the beginning of deposition of starch is, I think, of little significance. It depends on the relative activity of the leaves in making sugar and of the embryo in assimilating it. If much sugar is being made and growth of the embryo is slow, some of the excess sugar in the endosperm is condensed into starch; and it is deposited first in the region away from the direct route,—chalaza to embryo. It does not appear that early starch deposition has any determining effect on the final ratio of starch to protein.

Asparagine synthesis.—Both Schulze (12) and Prianischnikow (11) think that the synthesis of asparagine is a secondary process,—that asparagine is an intermediate form between the mono-amino compounds and protein. Schulze's conclusion is based on the fact that he finds in young legume seedlings, as asparagine increases, other nitrogen-compounds,—arginine, tyrosine, and leucine, decrease. Prianischnikow shows that on germination of seeds of Vicia sativa and of Lupine, a high percentage (65-75%) of the nitrogen-compounds is asparagine. Acid hydrolyses of these proteins by hydrochloric acid in vitro, on the other hand, gives a low percentage (0.5-3.5%) of asparagine, but more leucine. He thinks, therefore, that asparagine is formed during germination.

Glutamine.—During ripening of the wheat, no glutamine was found but much asparagine is present. According to Osborne's (10) analysis the percentages of aspartic acid and glutamic acid in the wheat proteins are:

	Gliadin, per cent	Glutenin, per cent
Aspartic acid	0.58	0.91
Glutamic acid	37.33	23.42

Glutamine may be a transitory substance formed just before drying of the grain, and so has been missed in the microchemical analyses. Further study is necessary here. A close series of microchemical tests of the changes in the nitrogen-compounds of the endosperm during germination should help.

Protein formation.—Formation of the storage proteins in wheat endosperm seems to be a condensation process, and takes place on desiccation of the grain.

The synthesis of artificial polypeptids from amino-acids has been accomplished by Emil Fischer, Grimaux, and others. One of the methods of synthesis is by dehydration:

—CO [OH H] NH—

On elimination of water this becomes

— NH — CO —

MICROCHEMICAL TESTS

Fructose.

1. Flückiger's reaction.—Red precipitate of cuprous oxide at once, **without heating.**

2. Phenylhydrazine reaction.—Yellow osazone crystals formed in 6-8 hours.

3. Methylphenylhydrazine reaction.—Specific for the ketoses (fructose and sorbose); since the osazone formed with sorbose is not crystalline, yellow crystal formation is specific for fructose.

Glucose.

1. Flückiger's reaction.—Red cuprous oxide crystals on heating 1-2 minutes.

2. Phenylhydrazine reaction.—Yellow osazone crystals after about 24 hours. If there is considerable sugar present the glucose and fructose osazone crystal-clusters are distinctly different, but this does not hold if there is little sugar.

Sucrose.

To remove fructose and glucose.—Flückiger's reaction,—heat 2-3 minutes; wash with dilute tartaric acid solution; warm concentrated magnesium chloride; tartaric acid.

Invert.—Invertase or hydrochloric acid.

1. Flückiger's reaction.
2. Phenylhydrazine reaction.

Starch.

1. Iodine-potassium iodide.

2. Observation with polarized light.

Fats.

1. Sudan III.—Red color.
2. Myelin formation.
3. Saponification.

Amino-acids and amides.

Crystallization.—Sections of tissue in absolute alcohol; crystals of asparagine, glutamine, tyrosine, leucine, proline and potassium nitrate may appear.

Identification.

1. Comparison with known crystal form. Asparagine crystals.—acute angle 51°.
2. Observation with polarized light.
3. Borodin's method.
4. Heat to 170°C.

Asparagine, Glutamine

Quinone.—Red Color.

Tyrosine

Millon's reaction.—Red color.

Arginine, Histidine

Picrolonic acid.—Yellow crystalline precipitate.

Leucine

Sublimation.

Proteins.

1. Biuret reaction.
2. Iodine-potassium iodide.
3. Xantho-proteic reaction.

Nitrates.

1. Diphenylamine-sulphuric acid reaction.—Blue color.
2. Brucin-sulphuric acid reaction.—Red color.
3. Nitron-acetic acid reaction.—Long needle crystals.

Phosphates.

1. Magnesium mixture. — Crystals of ammonium magnesium phosphate.
2. Ammonium molybdate-nitric acid.—Yellow precipitate of ammonium phospho-molybdate.

Magnesium Phosphate.

Ammonium.—Ammonium magnesium phosphate crystals.

Magnesium oxalate crystals.

1. Hydrochloric acid.—Soluble without gas formation.

2. Sulphuric acid.—Soluble without formation of sulphate crystals.

3. Calcium sulphate.—Calcium oxalate crystals.

4. Ammoniacal solution of ammonium chloride and sodium phosphate.—Crystals of ammonium magnesium phosphate.

Magnesium.

Formation of ammonium magnesium phosphate crystals.

Dissolved oxalates (potassium oxalates and others).

1. Uranium acetate.—Crystals of uranium oxalate.

2. Calcium nitrate.—Calcium oxalate crystals.

Potassium nitrate.

1. Crystallization.—Tissue in absolute alcohol.

Identification of crystals.—See Amino-acids.

Potassium.

1. Sodium cobalt nitrite.—Small yellow crystals of potassium cobalt nitrite.

2. Platinum Chloride. — Crystals of potassium-platinum-chloride.

Calcium.

1. 5% sulphuric acid.—Calcium sulphate crystals.

2. 2% oxalic acid.—Calcium oxalate crystals.

Calcium pectate.

1. 3% ammonium oxalate.—Calcium oxalate crystals; pectic acid set free.

2. Ruthenium red.—Red color.

Pectic acid.

1. Ruthenium red.—Red color.

2. Soluble in dilute sodium hydroxide, potassium hydroxide, and in alkaline salts.

Pectose (readily goes over into pectic acid).

1. Ruthenium red.—Red color.

2. Hydrochloric acid.—Alcohol (1:4); ammonia water; pectose dissolves.

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PLATE I.

LEGENDS FOR TEXT FIGURES*

Fig. 1.—Longitudinal section of young spikelet: g, glume; l, lemma; c, carpel; s, stamen; x 250. Fructose and asparagine are present in the primordia at tip of spikelet; glucose, arginine, histidine and some asparagine in the older floret as indicated in the legend on Plate I.

Fig. 2.—Longitudinal section of older spikelet: s, stamen; c, carpel; n, nucellus; x 250. Glucose is present in stamen; no starch; little asparagine; phosphate just beginning to come in. See legend Plate I.

Fig. 3.—Detail drawing of longitudinal section of stamen showing region containing phosphate.

Fig.. 4.—Young pollen containing fructose, pectin, magnesium and phosphate (probably magnesium phosphate); not starch.

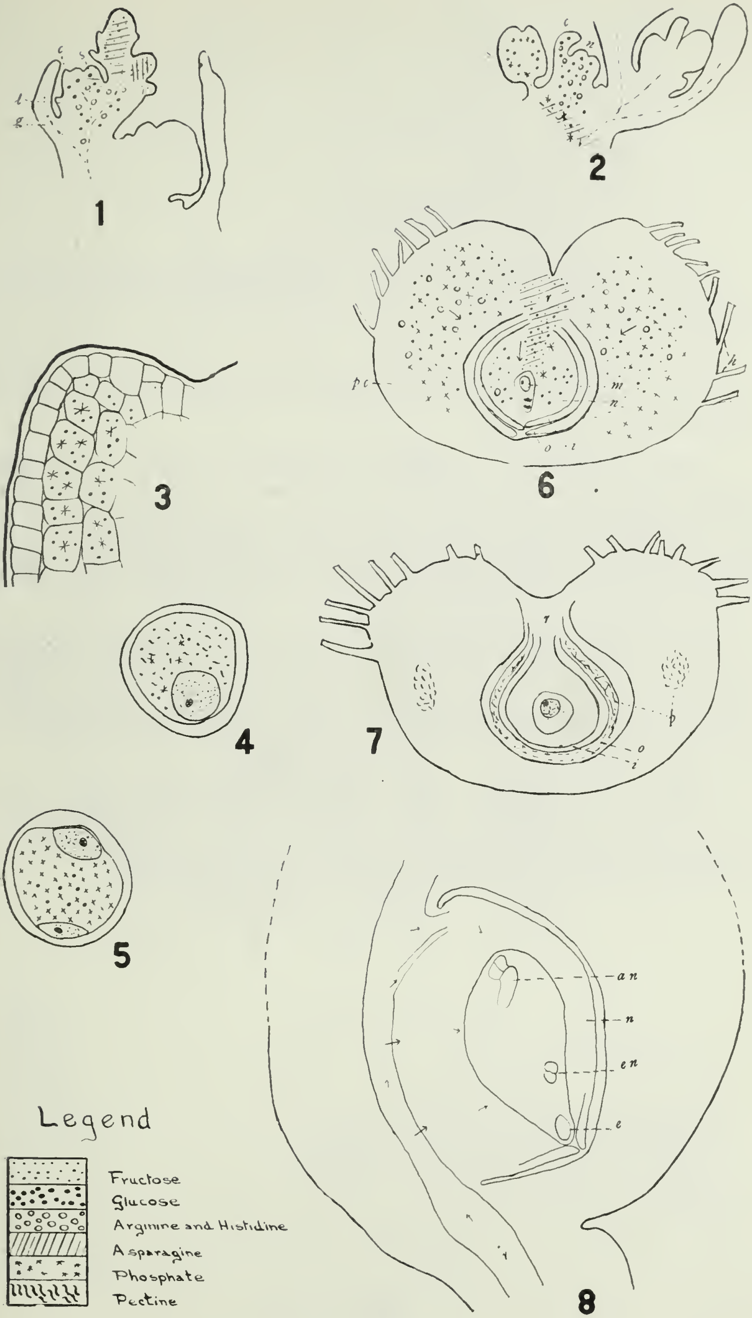
Fig. 5.—Pollen grain at time of shedding, containing trace of glucose, much starch; no free phosphate.

Fig. 6.—Transverse section of young ovule: r, raphe; m, megaspore; h, hairs on pericarp; x 500. Starch and amino acids in pericarp; asparagine, glucose, magnesium and phosphate moving thru tracheae of the raphe in toward the megaspore.

Fig. 7.—Transverse section of older ovule: outer integument and parenchyma tissue of the pericarp breaking down: r, raphe; i, inner integument; o, outer integument (breaking down); p, pectin. Much pectin.

Fig. 8.—Longitudinal section of ovule: pc, pericarp; r, raphe; n, nucellus; e, egg; en, endosperm nuclei; an, tissue developed from antipodal nuceli; x 50. Arrows indicate direction in which food substances are moving.

*Note.—The location of the various substances is indicated by symbols only in those tissues where the substances are present in proportionally large quantities and where their presence is significant in the metabolism of the developing wheat grain. (See legend, Plate I).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2
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Legend
Fructose
Glucose
Arginine and Histidine
Asparagine
Phosphate
Pectine

PLATE I.

PLATE II.

Fig. 1.—Part of plumose stigma; much pectin is present; pectic substance together with trace of glucose exudes from papillae at time of pollination; p, pollen grain.

Fig. 2.—Diagram of longitudinal section of culm at node below spike: 1f, leaf; st, stem; v. p., region of vascular plate shown in diagram, fig. 3.

Fig. 3.—Diagram of conductive system at node; the bundles cross over from side to side and from front to back forming a vascular plate at the node: lf, leaf; st, stem; v. p., vascular plate. Arrows indicate the direction in which the sugars are moving,—down the leaf to the vascular plate, thence up the stem to the spike. There is an accumulation of asparagine at the plate.

Fig. 4.—Diagram of longitudinal section of rachis to a spikelet; there are two vascular plates at the base of each spikelet: g, glume; l, lemma; gr, young grain; p, palea. Arrows show direction of movement of food substances. There is a large amount of asparagine at the vascular plate.

Fig. 5.—Cross section of seed coat of wheat grain: o. ep. p., outer epidermis of pericarp (cell walls chiefly of pectic substance); i. e. ep. p, inner epidermis of pericarp; t, testa (inner integument); n, nucellus membrane (suberized); al, aleurone layer of cells.

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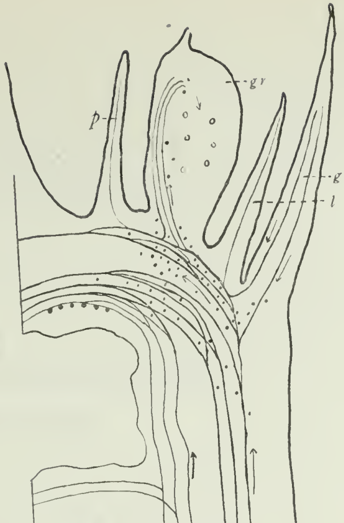

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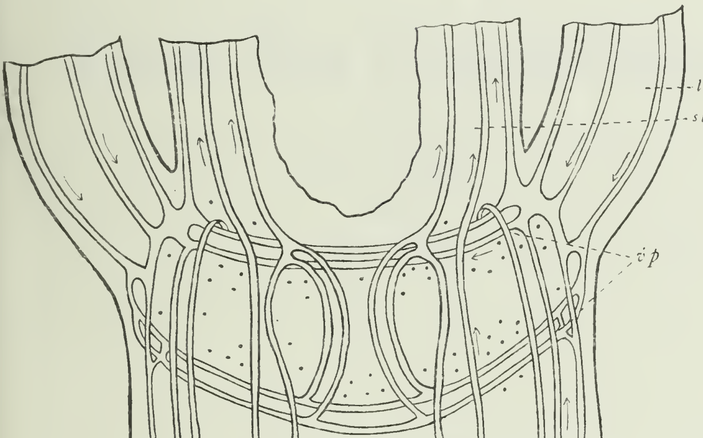

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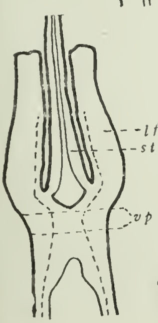

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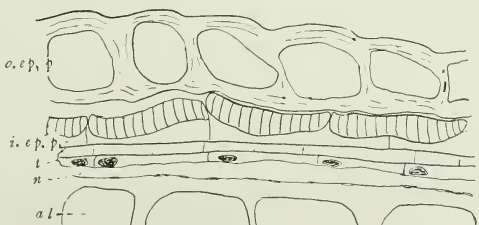

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PLATE II.

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF AGRICULTURE

Farm Crops

Field Pea Production

By

E. G. Schafer

and

E. F. Gaines

BULLETIN NO. 140

March, 1917

Field Pea Production

By

E. G. Schafer, Agronomist

and

E. F. Gaines, Acting Cerealist

Field peas are not grown extensively over a wide range of territory, but where conditions are suited to their production they often become a very important crop. A comparatively cool growing season is essential for their successful development, and they are resistant to frost except at the time of blossoming. High temperatures are unfavorable for field peas and hot weather materially decreases the yield of the crop. They require from 90 to 110 days to mature, depending upon the season and the variety. A fairly abundant supply of moisture is favorable for their growth, but the greater part of their development takes place early in the season before the moisture is lost from the soil by evaporation. They may thus be grown with less rainfall than crops which require a similar amount of moisture but mature later. This early development of the field pea insures its successful production in drier areas than would otherwise be possible.

Field peas succeed well on various soil types but produce best results on a loam or clay loam. Soils for pea production should be well drained and contain sufficient lime to prevent soil acidity.

The conditions suitable for field peas are found more generally in the northern tier of states and in Southern Canada. They have been grown more extensively in Canada than in the United States because the climatic conditions there are more favorable for their development. The higher summer temperature in the Southern states prevents their extensive production except as a fall seeded crop. In sections of Washington, where there is sufficient moisture, conditions are quite favorable for field pea growing.

VALUE OF GROWING FIELD PEAS

Summer fallowing is practised extensively in the grain growing districts of the state. This system of farming causes a considerable area of land to lie idle each year. Where there is sufficient rainfall much of the land which is summer fallowed might well be devoted to field pea production. It is generally considered safe to grow field peas in the place of summer fallow where the annual rainfall exceeds 16 to 18 inches.

A considerable quantity of grain hay is harvested in many places. Peas do well when planted in combination with oats or barley and add materially to the quality of the hay because of their high protein content. They are thus a valuable crop to be grown in grain hay mixtures.

There has been a considerable demand for field peas for seeding purposes and they usually have a much higher market value than wheat. They also make excellent feed for live stock.

Field peas leave the soil in excellent physical condition and the land may be seeded to wheat the same fall without plowing. The improvement of soil conditions resulting from growing field peas is one of the greatest benefits and is shown by superior yields of succeeding crops on field pea land. The fertilizing value of field peas will be greater if the crop is hogged off than if the crop is removed from the land for seed or forage.

PREPARING THE LAND FOR PLANTING

The land should be plowed in the fall and left rough during the winter. It should be further prepared in the spring by thoro disking as early as it is dry enough to work. If weather conditions do not permit fall plowing, the land should be plowed as early in the spring as possible and worked down immediately. Field peas should be planted in a rather deep, mellow seed bed.

INOCULATION OF THE SEED

Field peas, as well as other legumes, when properly inoculated, obtain nitrogen from the soil air thru their symbiotic relation with the bacterium *Pseudomonas radicicola*. They cannot obtain their nitrogen from the soil air unless they are

inoculated with the nitrogen gathering bacteria. Field peas and garden peas require the same kind of inoculation. A different kind is required for alfalfa and sweet clover, and still another for red, white and alsike clovers. The inoculation of the seed becomes one of the most important operations if the soil does not contain the bacteria at the time of seeding. A rank and vigorous growing crop of field peas is an indication that they are inoculated. Certain proof, however, is shown by the presence of clusters of nodules clinging to the roots of the pea plant when it is carefully removed from the soil. If the soil is not known to be inoculated, the peas should be artificially inoculated when planted. Bacteria culture is a commercial product and may be obtained from various sources in desired quantities and applied to the seed before planting. The commercial product contains the living organisms and it is essential that it be properly prepared and free from other bacteria. The use of the prepared bacteria culture is an economical and satisfactory method of inoculation.* Field peas may also be inoculated by spreading soil, from a field known to contain the proper bacteria, on the field to be seeded. If the soil used is thoroly inoculated 200 to 300 pounds should be sufficient for each acre. This soil should be worked in at once by harrowing or disking as the sunlight would be destructive to many of the bacteria.

TIME FOR SEEDING

In general, the seed should be planted as early in the spring as it is possible to get the seed bed in condition. As the field pea is adapted to growing during cool weather, it is able to make much of its growth before the hot weather of midsummer if planted early. Larger yields may be expected if planted early than if planted late. Under mild winter conditions, it may be desirable to seed in the fall. Fall seeding is sometimes practised in Western Washington as well as in other Pacific and Southern states.

AMOUNT TO SOW

The amount of seed to sow to the acre depends upon the size of seed, character of soil, and the amount of moisture

*Bacteria culture may be obtained from the Division of Farm Crops of the State Experiment Station at 25 cents per acre. Directions for the use of this material accompany each shipment.

available. The small seeded varieties contain more seeds in a given weight and should be planted at a correspondingly lower rate. As a result of experiments conducted at Pullman, Evans (3) recommended 75 pounds to the acre of the small seeded varieties such as Bangalia, and 90 to 100 pounds of the large seeded varieties.

Where moisture is the limiting factor of production the rate of seeding should be correspondingly less. As a result of tests in Central Washington where the rainfall is light seeding in rows was considered advisable by McCall (5). Row seeding is accomplished by seeding with the ordinary grain drill with part of the drill holes not seeding. The drill should be arranged so that two open holes alternate with four closed holes. The peas are thus planted in double rows three feet apart. This method of seeding materially decreases the amount of seed used. If this diminished amount of seed were planted evenly with all drill holes open there would be greater danger of competition from weeds. The system of planting in rows makes cultivation possible and the amount of seed used more nearly corresponds with the moisture available for the crop.

METHOD OF SEEDING

Field peas should be seeded at a uniform depth, and evenly distributed over the land except when seeded in rows. This is best accomplished by using a grain drill. They should be seeded at a depth of two to four inches. If the soil is a clay or clay loam, they may be seeded somewhat shallower than if the soil contains more sand. If the immediate surface is dry the seed should be planted sufficiently deep to be placed in contact with the moist soil.

Field peas may be seeded in a mixture with one of the grain crops. The grain crop serves to hold the pea vines off the ground and makes harvesting easier. It is especially desirable to include oats or barley with peas when the crop is to be grown for hay. Sixty pounds of peas and thirty of oats should be sufficient seed when a small variety like the Bangalia is used. Hunter (4) recommended that the peas be seeded first and that oats be seeded later when the peas have sprouts about two inches long. The sprouts usually attain this length in from six to ten days after planting. Oats grow a little more vigorously and this method prevents them

from crowding out the peas. Peas and grain have been grown successfully together when the seed of the two crops were mixed in the proportions desired and seeded in one operation.

HARVESTING THE CROP

Field peas should be cut for seed when the pods are mature and before there is great danger of loss from shattering. Often the vines do not ripen evenly and it will be necessary to harvest before all of the seeds are fully hardened. When seeded alone the field pea falls down badly and harvesting becomes somewhat difficult. They should be cut with the mower equipped with an attachment which raises the peas off the ground and allows the sickle bar to pass beneath them. This attachment consists of long guards extending in front and slightly above the sickle bar.

The mower should also be equipped for moving the swath away from the uncut crop and placing it in a windrow to prevent shattering which would otherwise result from driving over the peas the next time around. The device for this purpose consists of long curved rods attached to the rear of the sickle bar. An illustration of a mower equipped for harvesting field peas is shown in Fig I. The crop may be bunched with a fork from the windrow.

THRESHING FIELD PEAS

Field peas should be threshed directly from the bunch or windrow. The seed shells out easily and the crop should be handled as little as possible from the time of cutting until threshing. The ordinary grain separator may be used for threshing field peas. The seeds are easily broken and especial care should be exercised to reduce the amount of broken seeds to a minimum. It is necessary to remove the concaves, reduce the speed of the cylinder and adjust the straw racks to run at the regular speed, in order to properly thresh field peas.

DESCRIPTION OF FIELD PEA VARIETIES

The different varieties of peas described in Table I differ noticeably with regard to color, size, and time required for maturity. The color exhibited by the seed may be due to the color of the seed coat, the color of the cotyledons when the seed coat is semi-transparent, or to the combined effect of

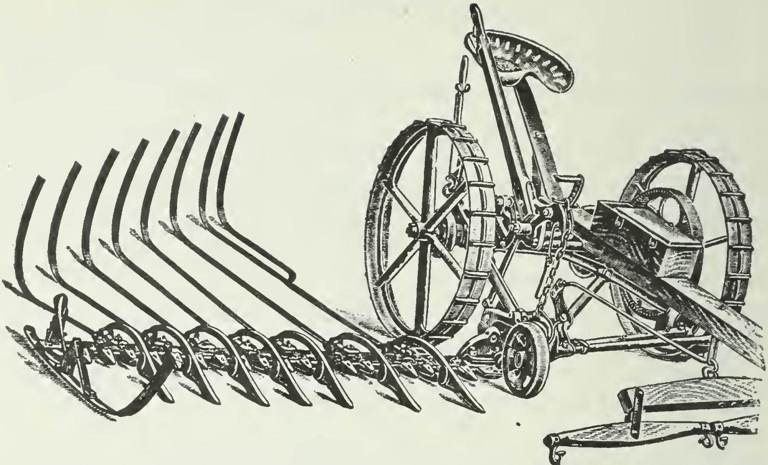

Fig. I. Lifters and windrower attachment for harvesting field peas. (Cut from F. Blocki Co., Sheboygan, Wis.).

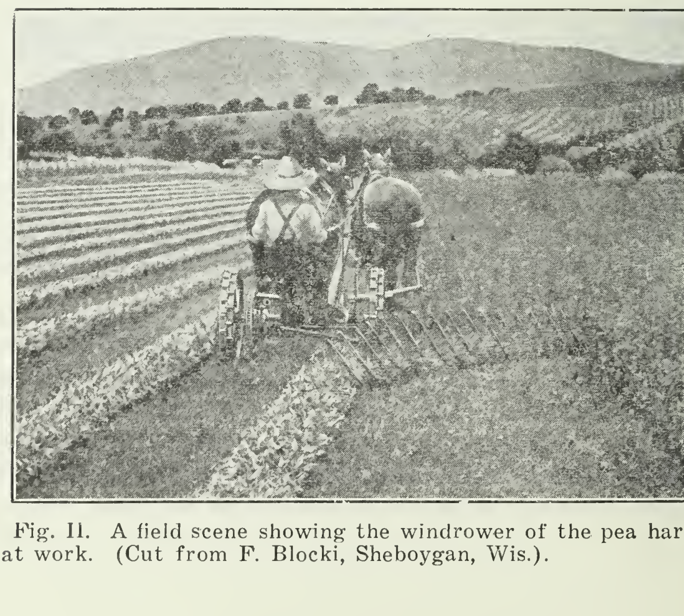

Fig. II. A field scene showing the windrower of the pea harvester at work. (Cut from F. Blocki, Sheboygan, Wis.).

the color of the cotyledons and the faintly colored seed-coat.

The comparative size of the seed of the different varieties is shown by the number of seeds contained in 20 grams. The range of variation extends from 139 in the Bangalia to 93 in the Blue Bell.

There is considerable variation in the date of maturity not only between different varieties but within the same variety for the different years. Bangalia matured as early as July 15th in 1915, and as late as August 19th in 1916, or a difference of 35 days in dates of maturing. The column "date ripe" gives the average time at which the different varieties mature during a period of three years.

TABLE I.

Tabular Description of Varieties of Field Peas

Variety	Wash. No.	Color of Seed	cotyledons	Size; No. of seed in 20 grams	Date ripe
Bangalia...	556	green	yellow	139	July 31
Smiley.....	557	white to light green	yellow	132	Aug. 3
Canada....	558	white to light green	yellow	108	Aug. 8
Amraoti...	559	white to light green	yellow	112	Aug. 7
Kaiser.....	554	gray with purple spots	yellow	102	Aug. 8
Blue Bell.	555	light blue green	green	93	Aug. 10
Alaska....	621	light blue green	green	98	

The **Bangalia** field pea was obtained from India by the United States Department of Agriculture in 1907. It produces a comparatively small seed which is slightly dented and dull green in color. It is the earliest maturing variety described in Table I and is one of the leading varieties grown in Eastern Washington.

The **Smiley** is also a small seeded and early maturing variety differing very little from the Bangalia with regard to size and maturity. The seed is nearly round and is white to light green in color. It is not extensively grown in Washington but seems well adapted for the eastern part of the State.

The **Canada** field pea described in Table I is one of many varieties designated by this name. It has a medium sized seed and matures rather late.

The **Amraoti** field pea is a medium variety with regard to size of seed, date of maturity and amount of vine produced. The seed is white to light green in color.

The **Kaiser** field pea was introduced into the United States from Germany. It is a fairly late maturing variety and has a medium large and dented seed which is irregular in shape. It is gray in color but covered with purple specks.

The **Blue Bell** has been grown in Western Washington where it has become a valuable variety. It was introduced from there into Eastern Washington. It has the largest seed and is the latest maturing variety included in the table.

The **Alaska** is used both as a field and garden pea. It is an early variety and has been extensively grown in certain districts of Eastern Washington. The seeds are nearly round often somewhat wrinkled, light blue-green in color and medium large.

TABLE II.

Yield of Varieties of Field Peas

Variety	Wash. No.	Bushels per acre				
		1913	1914	1915	1916	4-yr. average
Bangalia...	556	28.7	30.9	26.2	41.5	31.8
Smiley.....	557	32.7	24.7	27.0	39.2	30.9
Canada....	558	30.0	21.9	28.5	41.4	30.4
Amraoti...	559	35.4	19.2	22.7	29.7	26.7
Kaiser.....	554	19.2	21.1	21.0	31.0	23.1
Blue Bell..	555		26.7	21.7	44.8	
Alaska....	621				43.1	

Table II contains the yield per acre of five varieties of peas during a period of four years and two other varieties which were added after the test was begun. The variety Bangalia produced the largest yield per acre (31.8 bushels) for the average of four years. It will be noted that the small seeded, early maturing varieties stand at the head of the list in yield. In general the large seeded, later maturing varieties are less productive of seed.

VARIETIES TO GROW

There is a large number of varieties of field peas differing somewhat in their adaptability to environmental conditions. The early maturing varieties are generally better suited to sections of light rainfall. They reach a more advanced stage of maturity before the moisture is lost by evaporation and they escape much of the hot weather in midsummer which is unfavorable for their growth. The pea

Bangalia

Smiley

Canada

Amraoti

Kaiser

Blue Bell

Alaska

weevil which sometimes becomes a very serious pest is less injurious to the early maturing varieties. Late maturing varieties grown in sections where the climate, soil, and other conditions are favorable should make correspondingly heavier yields both of grain and forage.

The varieties producing smaller seed are injured less by cracking during threshing. It also requires a less amount by weight of the smaller seeded varieties to plant a certain area.

The results given in Tables I and II show that the Bangalia variety matured the earliest, had the smallest seed and produced the largest yield of any variety included in the four year test ending in 1916. Evans (3) found this variety to be one of the best of many varieties tested at Pullman, Washington, during a three years' test ending 1910. He also found that it produced the largest yield of six varieties tested at Ritzville, Washington, in 1910.

The Smiley is very similar to the Bangalia in yield and habit of growth, but has no apparent advantage and has not been extensively grown in Washington. Later maturing varieties than those used for seed production may be preferable if the crop is to be used for forage as the yield of seed becomes relatively less important.

There seems to be little difference in the quality of different varieties when fed to live stock, but some varieties are preferred above others when desired for human consumption.

UTILIZATION

The seed of field peas has a high nutritive value and makes an excellent feed for live stock. The following table compiled from Henry and Morrison's Feeds and Feeding, Sixteenth Edition, gives the comparative feeding value of peas, wheat, oats, and barley:

Crop	Total dry matter in 100 lbs.	Digestible nutrients in 100 lbs.				Nutritive
		Crude protein	Carbo-hydrates	Fat	Total	
Peas, field	90.8	19.0	55.8	0.6	76.2	1 : 3.0
Wheat..	89.8	9.2	67.5	1.5	80.1	1 : 7.7
Oats....	90.8	9.7	52.1	3.8	70.4	1 : 6.3
Barley..	90.7	9.0	66.8	1.6	79.4	1 : 7.8

Because of their relatively higher protein content peas are commonly fed in combination with some cereal.

The supply of field pea seed has not generally been abundant and the demand for the seed for planting has

made them too valuable to use extensively for feed. A considerable profit can often be realized by growing the crop for seed. The seed has also been widely used for human consumption.

The vines of field peas as well as the seed have a high nutritive value. When the crop is grown principally for seed the straw after threshing makes an excellent roughage for sheep.

Field peas planted with a small grain are often pastured or hogged off with good success. Ashby (1) reports the results of a feeding experiment in which he found that pigs make profitable gains when pastured on peas and oats with an additional grain ration. A lot of pigs which received three pounds of grain for each 100 pounds of live weight paid for their grain ration and returned a value of $46.41 for each acre of the pea and oat crop fed. The pigs were turned in when the early peas were commencing to harden. The field which was used for pasture produced a yield equivalent to about three and one-half tons of cured hay to the acre.

It is desirable to confine the hogs to a portion of the field by portable fences which may be moved so that new pasture may be furnished as soon as the first portion is cleaned up. If the hogs are turned into the entire field at once a considerable amount of the crop will be wasted. Pasturing may be commenced when the pods are well formed and the seed begins to harden.

A mixture of peas and grain also makes an excellent crop for hay or silage. Oats is one of the best crops to grow with peas for this purpose. A larger yield of forage is obtained than when the peas are seeded alone and the feeding value is greater than when the oats are grown alone. Pea and oat hay has about the same value as clover hay for feeding. The mixture of oats and peas can be harvested more satisfactorily and makes a better silage than peas alone. Varieties of peas and oats which mature at approximately the same time should be used when the two crops are grown together. They should be cut when the seed is in the dough stage.

TWO INJURIOUS INSECTS

In some places the pea weevil has become very destructive to the crop. The adult weevil which is a beetle lays its

eggs on the pods of the peas soon after the blossoms wither. The egg of the weevil hatches into a larva which bores thru the pod and into the growing pea.

The pea continues its development and when mature only a slight scar remains on the seed to show where the larva entered. The larva lies concealed within the seed and feeds upon the interior of it. The weevil remains in the seed thru the winter and often does not emerge until after the seed is planted. It then leaves the seed, works its way to the surface of the soil and completes its development..

If seed containing the weevil is used for planting, the weevil should first be destroyed. This may be accomplished by fumigating with carbon bisulfide. The seed should be placed in an air tight room or box and carbon bisulphide applied at the rate of one pound to each 1000 cubic feet of space. The carbon bisulfide should be poured into shallow containers placed on top of the peas. The room or box should be left closed for 36 to 48 hours. The temperature of the air should be 70° or above at the time the carbon bisulfide is applied as it will be more effective than at lower temperatures. The vapor of carbon bisulfide is inflammable when mixed with air and care should be taken not to use it close to a fire.

If the weevils have not broken the shells of the peas at the time of fumigation they may escape injury. Fumigation should therefore take place just prior to planting as more of the weevils will be out at that time than earlier.

Early maturing varieties of field peas are useful in avoiding weevil injury as the weevil does not commence laying its eggs until after the peas are too far matured for the weevil to seriously infest them. Shattered seed of a weevil infested crop should be destroyed by pasturing with hogs, or by disking which makes conditions more favorable for germination.

The plant louse or pea aphid occasionally causes serious injury to the pea crop. The aphid when present increases in numbers most rapidly during warm, dry weather and has been known to destroy a crop in a very short time. No effective measures have been devised for their control but rainy weather is unfavorable for their development.

SUMMARY

Field peas thrive best on a well drained clay loam soil where the growing season is cool and moisture is fairly abundant. They do well in many parts of Washington.

Field peas have been grown successfully on land that would otherwise be in summer fallow where the rainfall is 16 to 18 inches or above.

Field peas are of immense value in feeding live stock. The seed may be used as a concentrate or the vines may be used as forage.

Field peas leave the soil in excellent condition for succeeding crops.

Field peas should be inoculated with nitrogen gathering bacteria at the time of planting unless the soil is known to be inoculated.

Field peas should be planted as early in the spring as it is possible to get the seed bed in proper condition.

Field peas should be seeded with a drill at the rate of 75 to 100 pounds to the acre. The varieties with small seeds require a less amount to plant an acre.

In sections of light rainfall seeding in rows for cultivation becomes advisable.

The crop should be cut for seed before the major portion of the peas have fully hardened.

A mower should be equipped with a pea lifter and windrower for harvesting.

A grain thresher may be used for threshing the crop. The concaves should be removed and the speed of the cylinder reduced to prevent breaking the peas.

The smaller seeded, early maturing varieties have generally produced the heavier yields. The Bangalia produced the largest yield for an average of four years.

Field peas give excellent results when utilized by pasturing with hogs.

Field peas and oats make an excellent crop for hay or for silage.

The pea weevil may become very destructive to the crop. If the seed to be used for planting is infected the weevil should be destroyed by fumigation.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF AGRICULTURE
Farm Crops

Barley in Washington

By

E. G. Schafer

and

E. F. Gaines

BULLETIN NO. 141
March, 1917

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Barley in Washington

By

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and

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The average annual area devoted to barley in the State of Washington for the ten-year period ending 1915 was 175,799 acres. The average yield for the same period was 6,628,528 bushels. From the viewpoint of the total amount produced barley is of much less importance than wheat or oats, yet the comparatively high acre yield where barley is grown clearly shows its splendid adaptability. The following data compiled from the Year Books of the United States Department of Agriculture show the average area, production, and yield of wheat, oats, and barley in the State of Washington for the ten-year period 1906 to 1915.

TABLE I.

Name of crop	No. of acres	No. of bushels	Yield per acre in pounds
Wheat	1,762,020	39,858,226	1344
Oats	253,877	12,181,553	1533
Barley	175,799	6,628,528	1810

In this table barley is shown to produce heavier yields to the acre than wheat or oats, in the areas of the state devoted to these crops.

The results of the field variety tests of the Agricultural Experiment Station at Pullman, Washington, present further evidence of the superior yields of barley. Table II was compiled by using the average yield of the highest producing varieties of each crop included in the variety test. The table contains the yields for 1914, 1915, and 1916 and the average for the three years.

TABLE II.

Name of crop	Yield per acre in pounds			
	1914	1915	1916	Average
Spring wheat	2184	1724	3500	2436
Spring oats	2584	2144	3536	2756
Spring barley	2292	2476	4268	3012
Winter wheat	2868	2400	2328	2532
Winter barley	2708	2792	1692	2396

Fig. I. Distribution of barley in Washington 1909. Each dot equals 25,000 bushels.

The comparative yields of these crops in rod rows replicated three times supply still further evidence regarding this point. The ten highest yielding varieties of each crop, with the exception of spring barley of which there were only seven, were used in compiling Table III. The table contains the average yield of the various crops for 1914, 1915, and 1916, and the three-year average.

TABLE III.

Name of crop	Yield per plot in grams			
	1914	1915	1916	Average
Spring wheat	2739	2761	2819	2773
Spring oats	2822	2768	3271	2954
Spring barley	3513	3916	5253	4228
Winter wheat	2570	3111	3182	2954
Winter barley		3557	3255	

The average yields for the State and the results obtained from the experimental tests show that spring barley produces heavier yields than winter wheat, spring wheat, oats, or winter barley.

Barley does not have a wide range of distribution in Washington. Practically 85 per cent of the entire crop is produced in the five counties,—Columbia, Garfield, Walla Walla, Whitman, and Lincoln.

The early maturity of barley increases its range of adaptation. The data in Table IV were computed by taking the average date ripe of the various crops for the years 1913, 1914, 1915, and 1916.

TABLE IV.

Name of crop	Date ripe				
	1913	1914	1915	1916	Average
Spring wheat	Aug. 20	Aug. 1	Aug. 7	Aug. 25	Aug. 13
Spring oats...	Aug. 13	July 29	Aug. 5	Aug. 22	Aug. 10
Spring barley.	Aug. 6	July 21	July 22	Aug. 12	July 31
Winter wheat.	Aug. 10	July 22	July 25	Aug. 14	Aug. 2
Winter barley	July 28	July 10	July 13	Aug. 1	July 21

Winter barley is shown to mature twelve days before winter wheat and twenty and twenty-three days earlier than spring oats and spring wheat, respectively, but matures only ten days before spring barley. Barley thus surpasses wheat and oats in adaptability for short growing seasons. It may be grown to an advantage at high altitudes where early maturity is essential for successful production.

Barley resembles wheat in chemical composition and makes an excellent feed for fattening live stock, especially when it is used in combination with wheat, oats, corn, or peas. The value of the crop for stock feeding would seem to warrant its more extensive use for that purpose. Barley usually does not have a fixed place in the cropping system but can be made to take the place of other spring grains. An increase in barley production should go hand in hand with greater diversity in farming and increased live stock production.

DESCRIPTION OF VARIETIES

The varieties described in Table V show considerable variation in plant and grain characteristics. These differences are given in detail in the various columns of the table. The data recorded under height of plant and stiffness of straw were obtained by field measurements and observations. With the exceptions of Goldthorpe, Rice, and Chevalier there is but little variation in the height of plant of different varieties. The stiffness of straw was determined by the erectness of the crop at harvest time. The heavier yielding ability of some varieties was no doubt a factor in causing them to lodge. The variations given, which range from 50 to 90 per cent, therefore, are not caused alone from the variation in straw resistance but also from the variation in pressure due to weight of grain.

Varieties in which the grain threshes free from the glume and palea (chaff) are called naked. Those which retain the glume and palea after threshing are known as covered. All but four of the varieties described are covered. Two of the varieties have two rows of kernels and all other varieties have six rows of kernels to the head. The varieties further differ by the presence and absence of beards. In all cases where the beard is absent, except Arlington, the glume terminates in a triangular-like hood. The varieties in the table may be divided into six groups with regard to the above characters as follows:

1. Naked, six-rowed, and hooded.
2. Naked, six-rowed, and bearded.
3. Covered, six-rowed, and bearded.
4. Covered, six-rowed, and beardless.
5. Covered, six-rowed and hooded.
6. Covered, two-rowed and bearded.

TABLE V.

Tabular Description of Barley Varieties

Variety	Wash. No.	Height of plant in inches	Stiffness of straw in per ct.	Naked or covered	No. of rows	Bearded, beardless or hooded	Size: No. kernels in 5 gms.	Wt. per bu. in pounds	Date ripe
California	970	36.2	50.3	covered	six	bearded	119	49.4	August 1
Beldi..............	967	35.8	63.1	covered	six	bearded	118	47.7	August 1
Excelsior..........	959	35.5	63.0	naked	six	bearded	152	64.7	July 30
Nepal............	875	36.7	88.1	naked	six	hooded	169	64.4	July 31
Eureka (Nepal)....	958	36.0	85.2	naked	six	hooded	162	64.3	July 31
Blue............	973	36.0	63.4	covered	six	bearded	135	50.7	July 30
Beardless (Success)	873	38.4	75.9	covered	six	hooded	125	51.7	August 2
Goldthrope.........	961	41.9	93.2	covered	two	bearded	120	53.7	August 3
Rice..............	912	33.8	98.2	covered	two	bearded	109	54.0	August 3
Nepal..............	812	35.7	80.7	naked	six	hooded	150	64.6	August 4
Arlington..........	953	35.3	82.2	covered	six	beardless	163	51.7	July 30
Maryland...........	949	36.0	80.4	covered	six	bearded	132	50.0	July 19
Wisconsin..........	950	36.3	73.0	covered	six	bearded	120	49.7	July 19
Tapp...............	957	37.3	95.3	covered	six	bearded	132	48.0	July 26
Chevalier...........	971	33.7	92.8	covered	six	bearded	112	42.3	July 20
Hooded............	1172	37.0	96.5	covered	six	hooded	121	50.7	August 5

Further distinctions may be made with reference to length or compactness of head. With the exception of the last five included in the list all were grown as spring varieties.

The data regarding height, stiffness, weight per bushel and data ripe were obtained from an average of all records taken during the years 1913, 1914, 1915, and 1916. Where the crop was grown both in the field and nursery the data from each source was given equal value in obtaining these averages. The weight per bushel was determined from the 1915 crop.

California barley is a covered six-rowed bearded variety. It has a long open head and a tendency to weak straw. It is a spring variety and ranks first in yield of all the varieties.

The **Beldi** is similar in appearance to the California and ranks second in yield.

Blue barley has been grown extensively in Washington and has yielded well. The stems are bluish before the barley is ripe. It closely resembles California and Beldi. There is a tendency to group these three varieties together under the name of Coast.

The three **Nepal** varieties (Washington Nos. 875, 958, and 812) closely resemble each other in appearance. They have six rows, are hooded and thresh free from the glumes. The straw and chaff of these varieties is comparatively soft in texture.

The **Beardless (Success)** differs from the Nepal varieties in that the glumes adhere to the grain when threshed and the straw is more harsh.

The **Goldthorpe** and **Rice** are two-rowed varieties. They are covered and bearded and produce larger kernels than the six-rowed spring varieties. The Goldthorpe has a long slender head and the Rice has a club type of head. The Goldthorpe is the heavier yielder.

The **Tapp** variety is one of the most hardy varieties for fall planting but may be seeded either in the fall or spring. It is a six-rowed barley, with a club head and is bearded. The straw is very stiff and it stands up well even though a large crop is produced. Heavy yields may be expected from this variety when it comes through the winter without great injury.

The **Hooded** was developed at the Washington Experi-

Fig. II. Three important types of barley. 1. Tapp. 2. Beardless (Success). 3. Blue.

ment Station by crossing Rice and Beardless. It is a covered six-row hooded variety and has a club type of head. It is a winter variety, but unlike the other winter varieties is free from beards.

Maryland and **Wisconsin** are covered, six-rowed, and bearded varieties. They have the long, loose type of head. There is very little difference except that the Maryland has a stiffer straw and is a true winter variety. The Wisconsin matures grain when planted either in the fall or spring.

RSSULTS OF VARIETY TESTING

TABLE VI.

Yield of Barley Varieties—Nursery Test

Variety	Wash. No.	Yield per plot in grams					*Comparative yield
		1913	1914	1915	1916	Av. '14-'15-'16	
California.	970	4988	4049	3625	5668	4447	120.9
Beldi......	967	4302	4051	4127	5224	4467	121.5
Excelsior..	959	3569	3328	2955	4506	3596	97.8
Nepal.....	875	3400	2976	2952	3601	3176	86.4
Eureka....	958	2471	3175	2632	4218	3342	90.9
Beardless..	873		3884	3801	5270	4318	117.4
Blue.......	973		2984	3999	5211	4065	110.5
Goldthorpe.	961	3848	3473	3655	4478	3869	105.2
Rice.......	912		3247	3158	4180	3528	95.9
Nepal.....	812	2543	3066	2729	3690	3162	86.0
Arlington..	953		2127	2058	3284	2490	67.7
Maryland..	949			3298	3062		
Wisconsin..	950			2859	3501		
Tapp......	957			2488	4017		
Chevalier..	971			5374	3098		
Hooded....	1172			3718	3618		

*Average of the eleven varieties (3678 grams) was taken as 100.

Table VI contains the yield of varieties of barley tested in the nursery. The yield recorded each year for any variety is the total of three separate rod row plots. The average yield is the average for the three years 1914, 1915, and 1916. The varieties that have been tested for less than three years are not included in the average. The comparative yield is the yield reduced to a percentage basis in which the average of all varieties (3678 grams) is given a value of 100. All records given for Maryland, Wisconsin, Tapp, Chevalier, and Hooded are from fall seeding.

Table VII contains the yield per acre of nine varieties grown for three years in field plots and their average. It also contains the comparative yields which show the relation of each variety to the average of all varieties. The California

has given the highest yields of any of the varieties in the field tests.

TABLE VII.

Yield of Barley Varieties—Field Tests

Variety	Wash. No.	Yield per acre in bushels				*Comparative yield
		1914	1915	1916	Average	
California.....	970	49.2	57.8	89.6	65.5	114.7
Beldi.........	967	43.2	60.2	85.4	62.9	110.2
Excelsior.....	959	40.8	55.0	79.0	58.3	102.1
Nepal........	875	42.6	45.4	84.5	57.5	100.7
Eureka.......	958	36.8	52.8	74.7	54.8	96.0
Blue.........	973		58.7	87.5		
Maryland.....	949	50.6	76.3	40.8	55.9	97.9
Wisconsin.....	950	49.9	63.4	40.8	51.4	90.0
Tapp.........	957	68.9	59.4	24.6	51.0	89.3

*The average of all varieties (57.1 bushels) was taken as 100.

TABLE VIII.

Results from Nursery and Field Averaged.

Variety	Wash. No.	Nursery	Field	Average	Rank
California	970	120.9	114.7	117.8	1
Beldi	967	121.5	110.2	115.8	2
Excelsior	959	97.8	102.1	99.9	3
Nepal	875	86.4	100.7	93.5	4
Eureka	958	90.9	96.0	93.4	5

Table VIII shows a comparison between (1) the results obtained in the nursery and field, (2) the average results from the nursery and field, and (3) the rank in yield of varieties. It is possible to compare and give average results of the yields of the nursery and the field since they are reduced to a percentage basis.

SUMMARY

Barley is an important grain crop in Washington, but is grown extensively in a comparatively small area of the state.

Spring barley produces heavier yields than winter wheat, spring wheat, oats, or winter barley.

The value of barley for fattening live stock should be a factor in increasing barley production.

The straw of barley is not as stiff as that of wheat and oats and is more likely to lodge when a heavy crop is produced.

Winter barley matures earlier than any other grain. Winter wheat is next in order but matures on the average twelve days later than winter barley.

The naked six-rowed hooded varieties are less productive than covered six-row bearded ones.

Fig. III. A field of Tapp barley seeded in the fall, Experiment Station Farm.

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF CHEMISTRY

Gluten Formation in the Wheat Kernel

By

GEORGE A. OLSON

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Gluten Formation in the Wheat Kernel

By

GEORGE A. OLSON, Chemist

While it has long been recognized that enzymes are the active agents responsible for a vast number of catabolic processes occurring in the living cell, it was not until 1898 that van't Hoff (13) offered the suggestion that the action of enzymes is reversible and that the syntheses occurring in the organism might be brot about by enzymes. The first experimental evidence that this supposition is a correct one was brot forward in the same year by A. Croft Hill (4), who showed that the action of maltase obtained from yeast is reversible and that this enzyme brings about the synthesis of maltose from dextrose. Emmerling (3) subsequently showed that the compound here formed is not in reality maltose but the isomeric isomaltose. To Emmerling we also owe the discovery of another synthetic process brot about by maltase, since he has shown (3) that maltase constructs amygdalin from glucose and the glucoside of mandelic nitrile. Since these early discoveries, a number of hydrolytic enzymes have been investigated with reference to their power to accelerate synthetic processes in isolated substrates and under laboratory conditions, with such uniformly positive results that all physiologists have accepted reversibility of action as one of the distinguishing characteristics of enzymes. Since the products of such synthetic activities are identical with compounds found generally in the living cell, the presumption that such compounds are built up by the action of the enzymes found with them in the tissues is very strong. Some of the evidence for this belief, as for example that obtained from the study of the digestion, absorption and resynthesis of fat in the animal intestine or from studies of formation and digestion of starch in leaves, is well-nigh conclusive, but the nature of the process is such that we lack absolutely conclusive proof that any given synthetic process occurring in the living cell is controlled by an enzyme.

In this paper the writer will present data which tend to show that the formation of gluten in the wheat kernel is due to the synthetic activity of an enzyme. In a recent paper by Dr. Eckerson (2) a micro-chemical study of the development of the wheat grain has been presented.

Historical. The idea that enzymes function in the formation of gluten just as rennin functions in the curdling of milk is not new. Weyl and Bischoff (14), who heated flour previously extracted with 15 per cent. sodium chloride solution to the coagulation point of globulin and obtained no gluten therefrom, considered that gluten was the result of ferment action on pre-existing globulins. Martin (6) was also of the opinion that gluten did not pre-exist in flour. Johannsen (5) believed that gluten existed in wheat in a finely divided state. According to this writer, heating to a temperature of 60° C. did not injure the gluten of flour. Balland (1) believed as did Osborne (12) that gluten pre-existed in flour. O'Brien (8) found that heating flour to 100° C. for 13 hours did not alter the quantity of gluten extracted from flour. The last named investigator further found that the usual yield of gluten was obtained from paste made up of flour and boiling water and also from flour previously placed in alcohol or ether for twenty hours. Nasmith (7) states that "any manipulation that will destroy the hypothetical ferment will coagulate glutenin, thus making gluten formation impossible." Nasmith found that glutenin was coagulated at 70° C., while the paste made by O'Brien by stirring flour into boiling water did not reach a higher temperature than 52.5° C.

It consequently appears that the work of these investigators is not absolutely convincing. Treatment with absolute alcohol or ether for short periods does not destroy enzymes, nor does heating to 100° C. to 110° C. for short periods in the dry condition materially affect their activities. For these reasons the question whether gluten is formed thru the activity of an enzyme must still be considered an open one. In some work carried on in this laboratory during the past six years, a new method has been employed in attacking the problem, with the result that it has been possible to determine definitely that gluten is synthesized within the kernel. The method depends on the following facts: Freshly prepared gluten, when dried with the access of air at ordinary temperatures, loses the tough, coherent, elastic properties

which it originally possessed. If, however, the drying is conducted under reduced pressure, it may be carried on even at temperatures as high as 100° C. without alteration of the characteristic physical properties of the gluten.* This fact suggested that the drying of the entire kernels, under reduced pressure, might be accomplished without alteration of the character of the gluten present. Furthermore, the collection of a close series of samples, each of which was immediately dried under reduced pressure and subsequently analyzed with respect to its nitrogenous constituents, should enable one to follow any increase in the content of gluten as well as any concurrent changes in the character and amounts of the various simpler nitrogenous constituents present in the kernel. The synthesis of proteins in the wheat kernel has been followed in this manner as well as by microchemical methods (2).

One of the most perplexing problems confronting the writer in the earlier part of his investigations was the finding in most cases of gluten in wheat collected in the early stages of development. Occasionally the quantity present would be quite large, and in other instances very small. In making gluten determinations on a variety of wheat thruout its development, the gluten would sometimes increase up to a certain time after which the quantity present remained quite constant thruout the remainder of the development. In other varieties the yield, especially in the earlier stages, would be sometimes high and sometimes low, without any regularity whatever. In only two cases could the absence of gluten be explained as a result of the destruction of gluten by molds, since in all other cases the grains were normal in every respect and free from fungous attack.

The absence of gluten in some samples of grain and its presence in others of the same or greater age or stage of development, indicated that the synthesis of the gluten took place within the kernel thru the transformation of simpler nitrogenous constitutents into gluten by an enzyme. This view was supported by the fact that temperatures which suppressed the cell activities within the kernel were also the temperatures that suppressed the formation of gluten. The

*The process for preparing unmodified gluten is an important one, since it makes it possible to study the properties of this substance in a way hitherto impossible.

work of other investigators, and especially that of Nasmith, was opposed to this view in that these authors believe that the coagulation of the glutenin in itself would prevent the formation of gluten.

The fact that flour can be heated without materially affecting the gluten content and the further fact that the wet gluten can be dried at equally as high temperatures as flour without altering the tough, coherent and elastic properties of the gluten are in themselves opposed to Nasmith's views. The additional fact that wheat prepared by means of heating is devoid of gluten, while gluten is recoverable from flour heated to the same temperature, indicates that some chemical agent, such as an enzyme, is responsible for the transformation.

The first positive evidence that gluten appears in the wheat kernel only at a relatively late stage in its development was obtained in the season of 1911. In some observations made in that year it was noted that some kernels yielded no gluten when crushed to a pulp between the teeth. A few days later the wheat yielded small amounts of gluten upon like treatment, with progressively larger quantities on succeeding days. These observations indicated that the transformation of the gluten-free wheat to the gluten-containing condition is quite rapid, and also that it is associated with the process of desiccation, since the gluten appears shortly after desiccation sets in. Hence any wheat in which drying occurs under conditions analogous with those prevailing during natural desiccation in the field should contain gluten. Unfortunately, collections made in subsequent years for the purpose of testing out these conclusions have for the most part been made too late in the season, hence have contained considerable amounts of gluten. But the observed facts indicate that the investigations of Nasmith, Osborne and others have been made upon wheat in which the gluten had already been formed.

Having determined the fact that isolated gluten is not physically altered when desiccated under reduced pressure, and that gluten in wheat or flour heated to temperature of 100° C. at normal pressure is not affected, it is reasonable to believe that wheat when subjected to similar conditions would also contain gluten not physically altered.

For the 1914 experiment Jones' Winter Fife and Red

Russian wheat were selected in an early stage of development in order to determine whether or not gluten is present in wheat as such or is developed in the kernel as one of the final products in protein synthesis.

The Fife wheat was subjected to drying under reduced pressures at temperatures ranging from 30° C. to 50° C., inclusive. One lot was heated at temperatures between 30° C. to 35°C., another at 40° C. to 50° C., and a third lot at 50° C. and over. In each case it was the author's intention to keep the heating at the lowest initial temperature, e. g., the one lot at 30° C., the second lot at 40° C., and the third lot at 50° C., but irregularities in the degree of vacuum obtained by the use of an unsatisfactory pump made it impossible to hold the heating to the temperatures planned. It was impossible to maintain a uniform degree of vacuum for the experiment. The lot heated at 30° C. had the lowest vacuum and the one heated at 50° C. had the highest vacuum. The highest vacuum was obtained with the wheat heated to the highest temperature and the physical qualities or yield of gluten, if the gluten had been already formed, should not have been affected thereby. In addition one lot was allowed to dry in the open at room temperature. Conditions were made similar to those prevailing during the desiccation process taking place as the grain ripens in the field but any translocation which might take place in the field was of course eliminated. Six days later another sample was collected from the field and air dried for comparative purposes. The results for the Fife wheat were as follows:

TABLE I.

Effect of Temperature on Formation of Gluten, Fife Wheat, 1914.

No.	Temperature	Gluten Per cent wet	Gluten Per cent dry
1.	Control collected six days after other lots and air dried at 20° C.	27.30	11.00
2.	Dried at 20° C. in room	24.20	10.00
3.	Heated at 30° C. to 35° C.	22.50	9.60
4.	Heated at 40° C. to 50° C.	12.80	5.00
5.	Heated to 50° C. to 60° C.	1.40	.70

The Red Russian wheat was handled in a fashion somewhat different from that employed with the Fife. One lot was dried at room temperature, about 24° C., as a control, while the other was heated at 50° C. in a vacuum pan. Six days later another sample was collected and air dried at room temperature for comparative purposes. The results

for the Red Russian wheat were as follows:

TABLE II.

Effect of Temperature on Formation of Gluten, Red Russian Wheat, 1914.

No.	Temperature	Gluten Per cent wet	Gluten Per cent dry
6.	Control, collected six days after other lots..	23.40	10.60
7.	Dried in room at about 24° C.	20.80	8.00
8.	Heated in vacuum pan 50° C. to 60° C.	3.60	1.00

The first positive evidence that gluten is formed within the kernel and not translocated as gluten from other regions of the plant, is shown in the results obtained and recorded in Tables I and II. It is also evident that the higher temperatures have affected the substance or substances that bring about the transformation. While the wheat heated at 30° C. to 35° C. gives a gluten content somewhat lower than that found in the air dried wheat collected six days later, the yield is nevertheless high enough to indicate at least that the range of 30° C. to 35° C. under reduced pressure has not materially affected the transformation. The reduction of gluten in the case of wheat heated at 40° C. to 50° C. under reduced pressure (Table I) to less than one-half the amount found in the control, must be due to the destructive action of the higher temperatures employed with this lot of wheat, since at a temperature of 50° C. or above, under reduced pressure, there is practically no gluten present. The 1.4% wet or 0.7% dry gluten present in this lot of wheat is the gluten that was present in the sample when collected in the field and may be an amount present in a few kernels that had ripened a little ahead of the larger number under study. The observed facts further indicate that the suppression of the formation of gluten takes place at a temperature lying between 40° C. and 50° C. and a vacuum measurement of 40 centimeters or less. What has been stated with regard to Fife wheat is also true with reference to Red Russian wheat. The larger yield of gluten in the wheats collected six days later is due to the translocation or formation of additional material out of which the gluten is formed.

In an earlier article by the writer (9) it was shown that flour could be modified in such a way that practically no gluten could be obtained therefrom. This failure to obtain gluten occurred with flour from which the water soluble

materials had been removed by decantation. Upon the addition of a hydroxide—such as sodium, potassium, or calcium hydroxide or glycerol—it was possible to recover a part of the gluten, this recovered portion being geatest in the flour treated with sodium hydroxide, and least in that treated with glycerol. Consequently it was thot that the failure might possibly be due to the modification of the physical condition of the gluten. Flours prepared from wheats heated as described in the preceding paragraphs, when treated with sodium hydroxide, failed to yield gluten just as did the flour from which water-soluble constituents had been removed by decantation. Likewise, glycerol extracts of wheat and wheat plant failed to yield gluten. The distillate trapped from the heated wheat in the vacuum pan was also tried without results. Other substances, as well as enzymes, such as pepsin, trypsin, rennin and diastase, were used with the object of determining whether or not any of the known enzymes would form gluten in the flour obtained from the heated wheat with negative results.

All the investigations on enzyme isolation conducted thus far have failed to give positive proof that an enzyme is responsible for the change of the wheat grain from a gluten-free to a gluten-containing condition. It is not strange that the hydrolytic enzymes failed to produce any synthetic ac-

TABLE III.

Various Forms of Nitrogen Groups Separated from Flour, 1914 Crop.

No.	Total Nitrogen, per cent	1% salt soluble, Per cent.	Alco. insol. coagulable Per cent.	Alco. sol. Nitrogen Per cent.	Phosphotungstic ppt. Nitrogen Per cent.	Amide Nitrogen Per cent.
FIFE						
1.	1.34	.450	.093	.357	.170	.125
2.	1.46 (1)	.465	.108	.357	.170	.170
3.	1.40 (2)	.405	.085	.320	.215	.153
4.	1 50	.470	.095	.375	.170	.255
5.	1.50	.445	.045	.400	.165	.350
RED RUSSIAN						
6.	1.53	.525	.125	.400	.245	.120
7.	Not determined					
8.	1.55	.430	.050	.380	.190	.390

Numbers 1 and 2 repeated. The numbers in the extreme left hand column correspond with the numbers and order of the samples in Tables I and II.

tion, because enzymes affect or accelerate synthesis under entirely different conditions than is the case with hydrolysis. Further the transformation within the cell in undoubtedly very rapid as compared to laboratory hydrolysis.

In order to determine whether or not the protein materials in the kernel were affected by the different temperatures, separation of the protein groups were made according to the writer's method (10). The results of this investigation are recorded in Table III.

The nitrogen in the different samples of Fife varied from 1.34 to 1.50%. The two samples of Red Russian were more uniform; 1.53% nitrogen for the control and 1.55% nitrogen for the sample heated in the vaccum pan at 50° C. to 60° C. The most interesting nitrogen results observed were those obtained in the filtrates resulting from separating the phosphotungstic acid precipitate in the 1 per cent sodium chloride. Subjecting the wheat to temperatures of 40° C. or above resulted in a larger amount of nitrogenous material not being precipitated by phosphotungstic acid and appearing as amide nitrogen.

These results support the view that synthesis of the more complex nitrogenous substances was not completed at the time of harvest. The samples heated to a temperature that suppressed the transformation of the nitrogenous materials into the gluten product contained the largest amounts of amide nitrogen and failed to yield gluten. The wheat treated at a temperature of 40°C. to 50°C. gave only half the yield of gluten, but contained considerably more amide nitrogen than was found in either the sample heated at 30° C. to 35° C. or the control.

In view of the fact that the wheats were subjected to these temperatures under reduced pressure, it should not be assumed that the destructive temperatures at which the synthesis ceases are as high under normal pressure as those found in the 1914 investigation. On the contrary, it would be expected that under normal pressure the destructive temperatures would be considerably lower. At the time of the investigation the only logical procedure for conducting the experiment was under reduced pressure because under this condition it has been proven that the physical qualities of gluten are not altered.

The author had previously extracted the ether-soluble constituents from a preparation of gluten dried under re-

duced pressure without in any way modifying the physical characters of the gluten. It was thus proven that these physical properties are in no wise dependent upon the presence of ether-soluble materials, which may therefore be logically considered to be impurities mechanically held by the gluten.

In a series of experiments made in 1915, wheat was heated in an oil bath filled with Wesson's cottonseed oil, as such a bath gave more uniform temperatures than could be obtained with either the vacuum oven or the vacuum pan used in earlier work. The use of a water bath was prohibited by the discovery of the fact that it is impossible to recover more than a small part of the gluten present in flour which has previously been dialyzed in water, or in flour from which the aqueous extract had been decanted, but it was not known whether any alteration of the physical characters of the gluten present would result from subjecting wheat to the action of the bath of oil.

The ripening period came on earlier than had been anticipated, otherwise more complete information as to the effect of various temperatures upon gluten formation would have been obtained. The experiment was planned as follows: A number of identical samples of Red Russian wheat, collected by stripping the grain from the heads, which practice prevented the translocation of materials from other parts of the plant, were selected and four of these were immediately subjected to heating for one-half hour in the oil bath at 40° C., 45° C., 50° C., and 55° C. The three remaining samples were heated to 50 C. for one-half hour, after the expiration of 24, 48, and 66 hours. This time and temperature were selected since heating to 50° C. for one-half hour in the vacuum pan had been previously shown to entirely stop gluten formation. Portions of all the samples were subjected to moisture determinations, as it was the writer's belief that the formation of gluten was associated with the progressive desiccation of the grain.

A second experiment, in which Turkey Red X Bluestem hybrid—known as Washington No. 536—was employed, was carried out in exactly the same way, except that one sample was heated at 35° C. for one-half hour.

The third experiment with Marquis Spring wheat was conducted along lines somewhat different from those used with the two winter wheats above mentioned. The Marquis wheat was heated at a temperature of 40° C. and 50° C. for

various periods of 5, 10, and 20 minutes and in the case of the sample heated at 50° C., one was also run for thirty minutes. In all cases samples were kept for control purposes.

In order to overcome the fall in temperature resulting from the introduction of the wheat into the previously heated oil bath, the amount of cooling resulting from the introduction of a definite quantity of wheat was determined. The temperature of the bath was raised in each case to a point such that the fall resulting from the addition of the wheat would leave the whole at the temperature at which the experiment was to be conducted. The heated wheat was strained of surplus oil, washed repeatedly in gasoline and slowly dried at low temperatures under an electric fan. When partially dried, the wheat was again washed in gasoline and the drying continued. This operation was repeated until there were no further visible signs of oil on the wheat. The oil used was easily removed by this method of treatment.

The wheat heated at the various temperatures showed different shades of color, amber to green, after drying. Those dried at the lowest temperatures were amber colored, while those heated at higher temperatures were dark green. The wheats heated between the extreme temperatures varied in shade from nearly all amber and some green color for the wheat heated at the lower temperatures to green with some amber for those subjected to the higher temperatures. The few amber kernels were undoubtedly kernels removed from heads which had ceased to develop further or were more com-

TABLE IV.

Effect of Temperature on Formation of Gluten, Red Russian Wheat, 1915.

No.	Temperature	Gluten Per cent wet	Gluten Per cent dry	Water Per cent.
1.	Control—Air dried at room temp.	23.50 (0)	10.40	.....
2.	Heated at 40° C. 30 minutes	None	None	65.12
3.	Heated at 45° C. 30 minutes	None	None	65.12
4.	Heated at 50° C. 30 minutes	None	None	65.12
5.	Heated at 55° C. 30 minutes	None	None	65.12
6.	Heated at 50° C. 30 minutes after 24 hours	2.00 (1)	1.00	59.08
7.	Heated at 50° C. 30 minutes after 48 hours	12.80 (2)	6.00	40.23
8.	Heated at 50° C. 30 minutes after 66 hours	13.30 (3)	6.60	44.73

Number (0) gluten clean; number (1) contains much fibre; numbers (2) and (3) contain some fibre.

pletely desiccated than the general run of the sample. The presence of such kernels would account for the small traces of gluten that were found in the flour in the 1914 experiment.

Before entering into a discussion of the results obtained in 1915, it should be stated that it is not an easy matter to select grain carrying large quantities of flour that will not contain gluten. The sample of Red Russian wheat had not developed as far as desired, while the Turkey Red X Bluestem hybrid (Washington No. 536) and Marquis wheats had advanced too far to be of value in determining the effect of temperature on gluten formation.

The results recorded in Table IV for Red Russian are additional data showing that certain temperatures are destructive to gluten formation. Wheat containing 65% of moisture heated to temperatures as low as 40° C. gave a flour without gluten. Under normal conditions of pressure, heating to a given temperature appears to be more destructive than is found to be the case under reduced pressure.

With the dropping off of the mositure content from 65% to 59% there is some gluten formed. Sixty-six hours later with a moisture content of 44.73%, only 6.6% dry gluten was obtained, while in the control air dried sample in which drying extended over a longer period, 10.40% dry gluten was obtained. The lower moisture observed in case of the sample heated after 48 hours compared to that heated after 66 hours is due to some unknown cause producing considerably different rates of water loss from the two samples.

It appears that temperatures of 40° C. or below are destructive to gluten formation. There is also an indication that gluten formation does not take place when the moisture content of the grain is above 60%. Perhaps the formation does take place at a lower moisture content than 60% because some kernels are considerably drier than others and this in itself would account for the presence of some gluten. Our observations on the development of the kernel have shown that wheat does not fill after the moisture content has dropped to 40%. It may be that the formation of gluten is in some way related to the cessation of translocation of material into the kernel.

While it has been thus far impossible to isolate an enzyme which, when added to flour devoid of gluten, will cause the conversion of the nitrogenous constituents into gluten,

two facts have been determined which indicate strongly that an enzyme is active in the process. The fact that gluten formation is inhibited by heating to relatively low temperatures—40° C. to 45° C.—indicates that an enzyme is concerned in the process, since a chemical action not under enzymic control, would be accelerated, not retarded, by such a rise of temperature. The further fact that the process of desiccation accelerates gluten formation also indicates that an enzyme may be concerned, the action being accelerated thru the concentration of the solution of materials upon which it acts. The writer is inclined to believe that, altho the enzyme may be present in the wheat kernel from a very early stage in its development, it does not become active until the soluble nitrogenous materials in the kernel have become concentrated thru concurrent rapid translocation from the leaves and beginning desiccation.

In the series with Turkey Red X Bluestem wheat (Washington No. 536) the first lot was heated only to 35° C. This lot gave a rather surprising result, since there was at the time no reason to expect that a temperature less than 45° C. to 50° C. would have any material effect in stopping gluten formation. Four samples were used in testing the effects of progressive desiccation, one lot being tested at the end of each 24-hour period thru 96 hours. The results of the experiments with the Washington No. 536 wheat are given in Table V.

Table V.

Effect of Temperature on Formation of Gluten, Turkey Red X Bluestem Wheat (Washington No. 536), 1915.

No.	Temperature	Gluten % wet	Gluten % dry	Gluten Character	Water Per cent
1.	Heated at 35° C. 30 minutes	24.00	11.00	Very pliable	50.12
2.	Heated at 40° C. 30 minutes	25.40	11.00	Pliable	50.12
3.	Heated at 45° C. 30 minutes	25.00	10.90	Stiff	50.12
4.	Heated at 50° C. 30 minutes	24.20	10.80	More stiff	50.12
5.	Heated at 55° C. 30 minutes	23.00	10.40	Stiff, coarse	50.12
6.	24 hour period Heated at 50° C. 30 minutes	29.40	12.20	Firm, pliable	49.01
7.	48 hour period Heated at 50° C. 30 minutes	29.80	12.30	Fine quality	41.46
8.	72 hour period Heated at 50° C. 30 minutes	29.00	12.20	Fine quality	35.94
9.	96 hour period Heated at 50° C. 30 minutes	29.00	12.00	Fine quality	20.47
10.	Control	29.70	12.20	Fine quality slightly soft	

It is apparent from the data recorded in Table V that

the wheat used was too nearly mature for a satisfactory study of the enzyme action; there are nevertheless some interesting things brot out by the experiment. It is certain that the gluten forms in the presence of considerable moisture. This fact is supported by the data obtained in Table IV, which showed the presence of a trace of gluten in grain containing 59.08% moisture. Twenty-four hours after harvest all of the gluten in the Turkey Red X Bluestem (Washington No. 536) had formed. Comparing the temperature effects obtained for the first day of harvest it will be noted that heating to 35° C. was just as effective in stopping gluten formation as was heating to 50° C. or 55° C. This result would indicate that a temperature of 35° C. is destructive to the enzyme whose action results in the formation of gluten. If this temperature effect can be confirmed from further studies, the importance of temperature effects on the formation of gluten under field conditions should not be overlooked. It frequently happens that the temperature in the field reaches 35° C., and higher temperatures are occasionally reached. What influence external temperatures have on the temperatures within the kernel and whether or not the external temperatures have any effect on the gluten in the growing kernel is as yet undetermined. It is quite possible that the variations which are frequently observed in the gluten content of wheats with equal nitrogen content may be due to external temperature effects. This fact may partially account for variations in gluten content in some varieties of wheat as compared with others. The quantity of gluten present in a variety of wheat must undoubtedly also be influenced by the quantity of enzyme present, as well as by the amount of nitrogenous materials that can be transformed into the gluten product.

TABLE VI.

Effect of Heating for Various Lengths of Time on the Formation of Gluten, Marquis Wheat, 1915.

No.	Temperature	Gluten % wet	Gluten % dry	Character	Water Per cent
1.	Control	34.10	15.60	Soft, pliable	.....
2.	Heated at 50° C. 5 min...	30.40	14.00	Fair	49.28
3.	Heated at 50° C. 10 min..	30.40	14.00	Fair, stiff	49.28
4.	Heated at 50° C. 20 min..	30.00	14.00	Little too stiff	49.28
5.	Heated at 50° C. 30 min..	30.40	14.20	Little tough elastic	49.28

Samples heated at 45° C. not tested.

The Marquis spring wheat was subjected to temperatures of 40° C. to 50° C. for periods of 5, 10, 20, and 30 minutes. One series was heated at 45° C. but owing to the fact that the gluten had already developed in the wheat before harvest the results obtained with the series heated at the lower temperatures has not been recorded in Table VI.

Further work must be done before the relationships of temperature and moisture content of grain to the process of gluten formation can be known.

A few remarks with reference to the effect of the use of oil in these studies are timely. In all samples containing gluten the gluten content of samples heated in oil compares closely with that of controls. It is, therefore, evident that the oil has not in any way affected the gluten formed prior to heating in the oil bath. It had been shown in earlier studies that removal of the ether-soluble materials present in the gluten had no effect on the character or quantity of the gluten.

Data have been presented (Table III) showing that the wheats containing gluten contain much smaller quantities of the simpler forms of nitrogenous compounds (amide nitrogen) than were found in case of the wheats in which protein synthesis had been partly or wholly suppressed. In Table VII, additional data show the amino nitrogen to be much larger in amount in the Red Russian wheat of 1915 harvest in cases in which the temperatures applied were sufficiently high to suppress the transformation to more complex material. The data recorded in Table VII are results obtained by the use of Sorenson's formol titration method.

TABLE VII.
Amino Nitrogen in Red Russian Wheat, 1915, Formol Titration Method.

No.	Temperature	Number of cc. N/10 NaOH required per 100 grams of flour 1st stage	2d stage	Diff.	Per cent Nitrogen Animo Form
1.	Control	52.00	144.00	92.0	.192
2.	Heated at 40° C.	128.00	500.00	272.0	.381
3.	Heated at 45° C.	124.00	384.00	260.0	.364
4.	Heated at 50° C.	128.00	384.00	256.0	.358
5.	Heated at 55° C.	124.00	364.00	240.0	.336
6.	Heated at 50° C. after 24 hour period	120.00	344.00	224.0	.314
7.	Heated at 50° C. after 48 hour period	92.00	264.00	172.0	.241
8.	Heated at 50° C. after 66 hour period	104.00	272.00	168.0	.235

The results obtained and recorded in Table VII show more nitrogen in the amino form in the wheat immediately subjected to temperatures ranging from 40° C. to 55° C. than was found in the wheat heated to 50° C. after intervals of 24, 48, and 66 hours. The amino nitrogen content in the wheat heated at various intervals, compared with the untreated or control wheat, are in turn much higher than was found in the case of the control.

Evidently the process of heating in itself has slightly decreased the amounts of amino acids, for it is found that the wheat heated at temperatures higher than 40° C. contain progressively less nitrogen in the amino form than was found in the wheat heated at 40° C.

The number of cubic centimeters of N/10 NaOH required to neutralize the extract from 100 grams of flour in the first stage is high in all cases in which the nitrogen in the amino form is also high; the figures for the formol titration method agreeing well with the determinations of amino-nitrogen except in one case (No. 7 of Table VII).

Collectively the data in Table VII confirm what has been previously observed, namely, that the nitrogenous compounds in the wheat kernel are at first very simple in form, changing to the more complex form as the period of desiccation advances. The transformation is undoubtedly a synthetic process finally forming in the wheat the substance known as gluten.

The facts brot out in this study support the conclusion of Johannsen, Osborne, Balland, and O'Brien, that gluten exists as such in wheat or in flour made therefrom. In their investigations these workers employed grain in which the process of gluten formation had been completed prior to the harvesting of the wheat. Weyl and Bischoff also employed flour containing gluten, but these authors treated their flour samples with sodium chloride with the result that the gluten was thereby prevented from forming the usual compact mass.

SUMMARY

In the earlier stages of kernel development no gluten is found.

The formation of gluten takes place in the kernel at a time when translocation falls off rapidly. Desiccation also sets in at this time.

The conversion of the amino acids into gluten takes place very rapidly.

The formation of gluten is retarded or stopped by heating for periods of 10 to 30 minutes at 35° C. to 50° C. It is accelerated by the reduction of water content occurring in the grain with the beginning of desiccation.

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The Dipterous Families Sepsidae and Piophilidae

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The Dipterous Families Sepsidae and Piophilidae*

By

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and

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The species included in the following pages are commonly combined as the family Sepsidæ. As is shown in the discussion such a family is polyphyletic and justly must be separated into the two homogeneous groups Sepsidæ and Piophilidæ, each of which has more evident relationships with other acalyptrate families than the two have with each other. The splitting of the costa, the formation of the auxiliary vein and the development of the palpi are important ancestral characters which betray in this group separate lines of descent for the two families.

Economically both the Sepsidæ and the Piophilidæ are of importance since both are principally scavengers, feeding and breeding in filth, sewage, excrement, carrion and other decomposing vegetable or animal matter. Possibly it was such similarity of habits that led earlier entomologists to group all the genera together into a single family. The insects are not rare. Grass sweepings from any meadow, pasture or woodland will produce them. Species of Sepsis are particularly abundant and can be found on fresh dung where they run about with vibrating wings pirouetting in a unique and pretty dance. Possibly because of the commonness and familiarity of the species, possibly because of their filthy habits, the group has never been adequately studied. Becker called attention to the chaotic taxonomy of the European

*Contributions from the Zoology Laboratory of the State College of Washington.

species in his second paper on Egyptian diptera. "Diese bisher wenig untersuchten Formen einer von fast allen Schriftstellern stiefmütterlich und meist oberflaechlich behandelten Gruppe bieten des Interessanten und Neuen so viel, dass eine monographische Bearbeitung eine sehr lohnende Aufgabe sein würde." The North American species have been similarily neglected and even the commonest forms have not been identified. Through the kindness of Th. Becker, E. Brunetti and G. Strobl we have secured representatives of the commoner European species for comparison with the American forms, for species so closely associated with man and his domesticated animals are liable to have an extended distribution. While their identifications in one or two instances might be open to question yet their determinations and the clear figures recently published by Richard Frey showed that the common American species are some of them distinctive. Notably is this the case with *Sepsis cynipsea* which has been reported from America but which we have not recovered. The American specimens of what has been supposed to be this species are superficially like *cynipsea* but are apparently undescribed, although they constitute one of the widest spread and commonest of the species.

The senior writer turned over his collection of these insects in 1908 to Wm. M. Mann, who was at that time a student at the State College of Washington. Dr. Mann left the institution before completing his review of the group. In the meantime much additional material was gathered together, when the collection was submitted to the junior writer to be worked over as the basis of a bachelor's thesis. Since the presentation of this thesis the senior writer has entirely reconstructed and amplified the writings and reviewed every point, so responsibility for the following account is finally jointly shared by both authors.

While the greatest part of the material under review has been collected by the senior writer some of the specimens have been obtained through exchange with other entomologists, and several dipterists have furnished their findings in the group. In this last category come Dr. J. M. Al-

drich, Messrs. E. T. Cresson, Jr., Charles W. Johnson and J. R. Malloch, to whom we acknowledge grateful appreciation. In all nearly two thousand specimens have been studied. In citing distribution localities for the species later on the name of the collector is given in parenthesis. The following list includes names of the gentlemen who have made this review possible: J. M. Aldrich, C. F. Baker, G. Beaulieu, J. C. Bradley, C. T. Brues, Owen Bryant, J. R. de la Torre Bueno, G. Chagnon, A. B. Cordley, E. T. Cresson, Jr., R. W. Doane, E. M. Ehrhorn, G. A. Ehrman, Eldred Jenne, C. W. Johnson, F. M. Jones, W. Knaus, Rev. C. Livingston, W. M. Mann, C. W. Metz, A. P. Morse, W. Nason, H. T. Osborn, H. S. Parish, C. V. Piper, J. R. Randall, J. A. G. Rehn, W. T. Shaw, R. E. Snodgrass, M. C. VanDuzee. H. L. Viereck, A. J. Weidt, H. W. Winkley and M. A. Yothers.

Types of the new species are retained in the collection of the senior writer. Paratypes have been distributed, where borrowed, to the State College of Washington, the Philadelphia Academy of Natural Science, the University of Illinois, and to the collections of J. M. Aldrich and C. W. Johnson.

While the Sepsidæ are in nomenclatorial confusion their identification is not particularly difficult if too much reliance is not placed on color differences. The males present in their sex adornments characters that are distinctive and easily seen. The tubercles and spines of the legs are reasonably constant but the structures at the tip of the abdomen require interpretation because of the mobility of the parts. Decussate end-processes of the hypopygium may be only opposed; parallel processes may overlap, conspicuous pencils of hairs may be infolded, for the sclerites of the abdomen shift when drying and moreover the insects regulate when living the degree to which their genitalia are displayed. Because of the rigorous flexion of the front legs following death the males of Sepsis should have their tibiæ extended when being mounted in order to facilitate ready determination of the species. In dried material it is possible by careful manipulation to spring open the front knee by using a microscopically hooked needle point. Too much tension must not be exerted or the legs will sever at the coxa: all that

is necessary is to open sufficiently to expose the armature on the flexor surfaces. A binocular microscope, here as elsewhere in the study of micro-diptera, greatly facilitates identification and proves to be almost indispensible.

The dominant genus Piophila will give the student some trouble because of a variability of color and lack of structural character. He will sympathize with Schiner who felt that die Arten sind in der Färbung so veränderlich und in der Hauptsache doch wieder so sehr übereinstimmend, dass ihre Unterscheidung mit grossen Schwierigkeiten verbunden ist, um so mehr, da viele Varietäten als Arten behandelt worden sind und von Andern auch als solche wieder angsehen werden dürften, wenn auf die Veränderlichkeit der Färbung kein Bedacht genommen wird.

The distinctive characters whereby the Sepsidæ and Piophilidæ differ from each other are listed herewith:

Sepsidæ. Auxiliary vein curving forward so as to terminate obviously before the end of the first vein, costa not broken, third and fourth veins slightly converging; palpi vestigial; face carinate, gena very narrow, reduced to an orbital line, bucca fringed with hairs graduating into the oral vibrissæ; abdomen often constricted at the second segment and often bearing a few bristles; front legs of the males often deformed; usually two scutellar bristles; mesonotum aciculate or pollinose and not pubescent, its setulæ usually in three longitudinal rows.

Piophilidæ. Auxiliary vein terminating close to the end of the first longitudinal vein, the costa broken at or near the termination, third and fourth veins parallel or slightly diverging; face flattened, gena not differentiated as a linear orbital boundary, bucca rarely fringed with hairs, the oral vibrissæ usually very prominent; abdomen devoid of bristles; front femora of the male not toothed or deformed; palpi well developed; four scutellar bristles; mesonotum almost always finely pubescent and polished.

Family SEPSIDAE

Head more or less spherical, the occiput usually quite convex, face carinate; one or two pairs of vertical bristles, one or no orbitals, postvertical bristles divergent; antennæ decumbent, the third joint oval, the arista usually bare; gena very narrow, reduced to an orbital line; palpi vestigial. Meso-

notum usually aciculate or pollinose and not pubescent, its setulæ usually in three longitudinal rows; scutellar bristles usually two rarely four in number; either one or two pairs of dorsocentral bristles; sternopleuræ usually in part or entirely pruinose. Auxiliary vein curving so as to terminate obviously before the end of the first longitudinal vein, costa not broken, the third and fourth veins more or less converging; anal vein straight and abbreviated. Legs of the male usually deformed and armed with spines or thorn-like projections, usually located on the front pair. Abdomen with but sparse pubescence or fine setulæ, often constricted at the second segment and bearing a few bristles; male genitalia usually prominent, symmetrical, comprising a hypopygium with paired lateral valves each tipped by a prong or flat blade of distinctive structure; ovipositor not extended, the female abdomen with bluntly rounded termination.

This family includes small slender flies which breed in dung and carrion and are so commonly met with that they have been largely shunned by systematists. Undoubtedly some of the commoner species which live in association with man have been spread by commerce over much of the world, but unfortunately the taxonomy of even such widely distributed species is unsettled. We have received different species bearing the same name from several correspondents and a glance at the check lists shows that authors have been confused in their identifications. Thus absolute credence can not be placed on the determinations of the published records. Where, however, American species appear to differ in no tangible way from European comparison material we have followed the plan of using the name furnished by our European correspondents, rather than to coin new species names pending the settlement of the appropriateness of the names in general use in Europe. While this course is open to some criticism it appears to us better to err by extending the distribution of a known species than to erect new species on geographic data alone. The figures following the account will help to fix species limitations as we have conceived them. Unfortunately the earlier descriptions are too brief to be in-

telligible; their generic location is even problematical; it is quite possible that some of the species are not Sepsidæ, for the older definitions of the family called merely for vibrating wings, rather long legs and spherical head. The Sepsis habitus has been developed independently in several groups of diptera, as, for example, in three subfamilies of the Ortalididæ, represented by the genera Myrmecothea, Myrmecomyia and Sepsisoma.

The known genera of Sepsidæ may be distinguished by the following table. Brief notes on the exotic genera follow the tabulation but those groups that include North American species are described and analyzed to the species. The inclusion of the exotic genera from the data furnished alone by their descriptions has necessarily destroyed the phyletic arrangement of the key.

KEY TO THE GENERA OF SEPSIDAE

Oral bristles more or less evident; anal vein interrupted before the wing-margin; abdomen relatively broad and but little longer than the thorax. 2.

No oral bristles; anal vein reaching wing-margin; abdomen narrow and more than twice as long as the thorax; arista pubescent; hind femora lengthened and thickened and short-spinose beneath; third and fourth veins parallel, second basal and anal cells long (Europe; Oceanica; No. America ?). MEGAMERINA Rondani

2. First segment of abdomen relatively short; scutellum not tuberculate. 3.

First segment of abdomen nearly as long as the remaining segments together; scutellum with two setigerous thorns. (Africa). CENTRIONCUS Speiser

3. Scutellum convex, transversely triangular; vibrissae not strongly developed, the vibrissal angle of the cheeks reduced, cheeks less than one-fourth of the height of the eye; dorsum of thorax and abdomen convex; first and second basal cells separated. 4.

Dorsum of thorax and of abdomen slightly convex; scutellum flat, as long as wide; vibrissal angle of cheeks prominent, the single vibrissa strong, cheeks one-fourth as wide as eye-height; first and second basal cells completely fused; two vertical, one orbital and four scutellar bristles present. (Europe; Asia; North America). PANDORA Haliday

4. Face never bearded, hind femora never shaggy; vertex less bristly; scutellum usually bisetose. 5.

Face ♂ bearded; hind femora ♂ with dense long pile; vertex with about ten strong bristles; mesonotum pubescent; scutellum quadrisetose. (Europe). AMPHIPOGON Wahlberg

5. Vertex bearing two vertical bristles on each side, fronto-orbitals usually weak or wanting; abdomen usually constricted between the first and second segments; wings sometimes with subapical spot. 6.

Vertex bearing a single bristle on each side; front legs ♂ more or less deformed; sternopleurae entirely pruinose; wings not spotted. 8.

6. Front femora ♂ sometimes bearing one or two flexor thorns or bristles but in neither sex with a close-set row of spines; ventral segments simple or at most with inconspicuous processes. 7.

Front femora ♂ ♀ with a row of close, uniform, black spinules or setulae beneath, those of ♀ forming a pecten along the apical third of the femur; one pair of dorsocentrals; legs of ♂ not deformed; last ventral segments of ♂ abnormal with hamate processes. (Cosmopolitan). NEMOPODA Desvoidy

7. Abdomen ♂ always, ♀ sometimes, bearing a few macrochaetae; fronto-orbitals usually absent; two dorsocentrals usually present; sternopleurae often entirely pruinose; wings with the costal cell always clouded and the end of the second vein usually surrounded by a subapical spot; front femora ♂ tuberculate, of ♀ without any projecting flexor bristles; process of hypopygial valves usually gradually acuminate and terminal. (Cosmopolitan). SEPSIS Fallen

Abdomen devoid of macrochaetae, but the swollen terminal segments ♂ with long hairs; front femora ♂ not tuberculate but bearing flexor bristles; wings with subapical spot; no fronto-orbitals, two dorsocentrals; sternopleurae entirely pruinose; small species. (Europe; North America). SEPSIDIMORPHA Frey

Abdomen devoid of macrochaetae; one fronto-orbital and one dorsocentral present; sternopleurae largely polished; wings uniformly hyaline; front femora ♂ not tuberculate but with a stout, blunt thorn and an adjacent strong flexor bristle, of ♀ with a single flexor bristle near the middle; process of hypopygial valves abruptly slender and inferior. (Europe; North and South America). MEROPLIUS Rondani

8. Postvertical and fronto-orbital bristles small; abdomen constricted between the first and second segments. 9.

Postvertical bristles long; one evident fronto-orbital; abdomen

not constricted toward the base. (Cosmopolitan).
THEMIRA Desvoidy

9. Lower part of face protruding; front coxae as long as their femora; abdomen with six segments; entirely matt black species. (Africa). AMYDROSOMA Becker

Lower part of face receding; front coxae shorter than their femora; abdomen with five pregenital segments; body mostly shining and subshining. (Europe; North America).
ENICITA Westwood

Genus **SEPSIS** Fallen

Fallen, Spec. Ent. Meth. Exhib., 17 (1810); Faun. Suec., Ortalid., 20 (1820)

Meigen, Syst. Zwfl. Ins., V. 285 (1826)

Schiner, Faun. Austr. Dipt., II. 177 (1864)

Wulp, Tijdschr. Ent., VIII. 129-143 (1864)

Rondani, Bull. Soc. Ent. Ital., VI. 174 (1874)

Frey, Deut. Ent. Zts., 1908, 579 (1908)

Acrometopia, Lioy (not Schiner) Atti Inst. Veneto. ser. 3, IX., 1088 (1864)

Beggiatia Lioy, Atti Inst. Veneto, ser. 3, IX. 1088 (1864)

Head globular occiput rounded; two vertical bristles each side; fronto-orbital bristles absent; oral bristles hair-like, no distinct vibrissa. Notum of the thorax usually not polished; acrostichal setulæ forming two outer rows and an inner irregular row in the middle, dorsocentral bristles comprising one or two pairs; one pair of apical scutellar bristles; one humeral, two notopleural bristles; sternopleuræ usually white-pruinose, except in the tropical forms; wings generally with a conspicuous subapical spot surrounding the end of the second vein; front femora of the male variously deformed, the under side bearing spines or bristles and sometimes decidedly tuberculate. Abdomen constricted between the first and second segments; the third, fourth, fifth and sometimes the second segments bearing macrochætæ, which are absent in the females of some species.

Genotype, *S. cynipsea* Linneus, by designation of Curtis, Brit. Ent., 245 (1829).

The species of Sepsis are common and can be collected by the sweeping net in any meadow or field particularly where there are droppings of horses or cattle. As they frequent

dung, garbage or carrion such filth can be counted on to yield many specimens. In contrast to their disgusting habitat the species are really beautiful little insects and with their curious habit of pirouetting about with extended vibrating wings they attract attention by their dainty dance.

As the males offer excellent characters available for identification of the species and which are not shared by the females we offer two tables of the North American species based on the separate sexes. In places the table for the females is unsatisfactory owing to a lack of constant and distinctive characters. The description of *Sepsis fulvicoxalis* Bigot is too meager to admit placing this species in the table.

KEY TO THE NORTH AMERICAN SPECIES OF SEPSIS

Based on the Male.

1. Wings without a definite subapical spot; sternopleurae polished in large part, at least as far as known; lamellæ of the hypopygium with an acuminate process at the middle of the inner edge. Tropical species. 2.

   Wings with a distinct darkened spot at the end of the second vein; sternopleurae entirely pruinose; valves of the hypopygium without a process at the middle of the inner edge. 8.

2. Pleurae wholly or almost wholly reddish or yellow; abdomen opaque, scabrous and more or less blackish. 3.

   Body black, legs more or less black; abdomen polished; notopleural suture pruinose. 4.

3. Upper part of the head, the center of the meso- and metanotum and the dorsum of the third, fourth and the base of the fifth segments of the abdomen black. **pleuralis** Coquillett.

   Head and thorax more or less reddish, without the black coloration above, the abdomen entirely black except the hypopygium. **discolor** Bigot.

4. Color brassy green; antennae and tarsi yellow; notopleural suture conspicuously white-pruinose. **ecalcarata** Thomson.

   Color blue black or green black; antennae and the apex of the tarsi more or less darkened; notopleural suture less conspicuously pruinose. 5.

5. Front metatarsi excised on the apical third of the anterior side; front tibiae and femora with flexor tubercles; valve of hypopygium with a broad but acute apex; anal vein almost attaining the margin. **hoplicnema**, n. sp.

   Front metatarsi uniformly cylindrical; front legs not strongly

tuberculate, although deformed; apex of hypopygial valve slender. 6.

6. Front femora with a flexor bristle toward the base; middle process of the hypopygial valve very broad; anal vein extending less than half-way to the margin. 7.

Front femora without a basal bristle but with a short stiff flexor bristle near the middle before the deformity; middle process of hypopygial valve very narrow; anal vein reaching more than half way to the margin. **insularis** Williston

7. Apex of middle tibiae distinctly blackened; basal third of front tibiæ scarcely excised; no distally projecting thorn-like bristle from the femoral swelling. **armillata**, n. sp.

Middle tibiæ not black at the apex; basal third of front tibiae strongly excised; a thorn-like bristle projecting distally from the swelling underneath the front femora. **furcata**, n. sp.

8. Posterior pair of dorsocentral bristles alone present; two bristles before the irregular cusped tubercle of the front femora; front tibiae never greatly arcuate; end-process of hypopygial valves short and more or less angled; second segment of abdomen devoid of macrochaetae; calypteres blackish and fringe dusky. (**violacea** Meigen) 9.

Two evident pairs of dorsocentral bristles, if abnormally the anterior pair is lacking then otherwise disagreeing with the preceding description. 11.

9. Bristles of the middle and hind tibiae much reduced; legs largely blackish. var. **hecate**, n. var.

Middle femora and hind tibiae each with one or two bristles; legs largely yellowish. 10.

10. Middle tibiae with one outer and one inner bristle; acrostichal setulae usually wanting. var. **violacea** Meigen

Middle tibiae with two or three outer and one innner bristle; acrostichal setulae present, though minute. var. **similis** Macquart

11. Calypteres and fringe pale; middle femora with two strong bristles near the middle of the anterior side, middle tibiae with three bristles, bristles of hind tibiae strong, hind tarsi setulose underneath; acrostichal and dorsocentral setulae strong; legs stout, the front femora setose beneath and with one (or abnormally two) stout spines proximal to the tubercle, the front tibiae biarcuate and with a cluster of setulae on basal third; pectus and often humeri and venter yellowish; end-process of hypopygial valves long, narrow and not decussate; length 5 mm. **pectoralis** Meigen

Calypteres dusky; middle femora rarely with two, usually with

one or no bristles; middle tibiae usually with two or one smaller bristles on the outer edge; bristles of hind tibiae not pronounced; front tibiae more slender; thorax and venter rarely exhibiting a yellow color. 12.

12. Tubercle of front femora not dentate; process of hypopygial valves terminal; second and sometimes first segments of abdomen with bristles. 13.

Tubercle of front femora with a pronounced distal tooth; process of hypopygial valves arising before the apex; first and second tergites not furnished with bristles. **luteipes,** n. sp.

13. End-process of hypopygial valves less slender and decidedly decussate; front femora not seriately setose beyond the tubercle (except sometimes in *vicaria* which has the legs largely yellowish); fringe of calypteres dusky. 14.

End-processes of hypopygial valves long and nearly or quite parallel; under side of front femora with a distal series of two to four setae; front tibiae not strongly sinuate; legs largely black; hairs of calypteres pale yellow. **neocynipsea,** n. sp.

14. Front femora stout, more spinose beneath, the tubercle setulose in addition to the spines; front tibiae strongly sinuate; veins and pedicel of halteres blackish, last section of fifth vein subequal to posterior crossvein. (**signifera,** n. sp.) 15.

Front femora slender, beneath with only a central spine and a group of three or four spines on the tubercle; front tibiae weakly sinuate; legs yellowish; veins yellowish brown. 16.

15. Legs mainly yellowish, the front femora with two spines before the tubercle; mesonotal setulae strong; anterior crossvein at apical third of discal cell. var. **signifera** n. var.

Legs nearly or quite black, the front femora with a single spine before the tubercle; mesonotal setulae not strong; anterior crossvein before apical third of discal cell. var. **curvitibia,** n. var.

16. Body largely red in color, including the pleurae, sides of the notum, scutellum and base and apex of the abdomen; tubercle of front femora undeveloped but with five equidistant uniform spines. **pyrrhosoma,** n. sp.

Body entirely black; spines of femoral tubercle irregular. **vicaria** Walker

TABLE OF THE NORTH AMERICAN SPECIES OF SEPSIS.
Based on Females.

1. Wings without a definite subapical spot; sternopleurae for the most part polished; tropical species. 2.
   Wings with a distinct subapical spot; sternopleurae entirely pruinose. 6.
2. Pleurae wholly yellow or reddish; largely yellow species with the abdomen opaque, scabrous and more or less blackish. 3.
   Body black in color, the legs more or less blackish, the abdomen polished; notopleural suture pruinose. 4.
3. Upper part of head, center of meso- and metanotum and dorsum of the third, fourth and the base of the fifth segments of the abdomen black. **pleuralis** Coquillett.
   Head and body reddish, without the black colorations above mentioned. **discolor** Bigot.
4. Color brassy green; antennae and tarsi yellow; notopleural suture conspicuously white-pruinose. **ecalcarata** Thomson.
   Color blue-black or green-black; antennae and apex of tarsi more or less darkened; notopleural suture less evidently pruinose. , 5.
5. Anal vein short, extending less than half way to the margin. **furcata**, n. sp. and **armillata**, n. sp.
   Anal vein reaching more than half way to the margin. **insularis** Williston
6. Head and thorax largely reddish, legs entirely light yellow; sides of first tergite with a single bristle. **pyrrhosoma**, n. sp.
   Head and thorax mostly or wholly black; legs reddish yellow or more or less blackened. 7.
7. Notum with but one pair of dorsocentral bristles; abdomen with distinct macrochaetae. (**violacea** Meigen) 8.
   Notum with two pairs of dorsocentrals; abdomen without distinct macrochaetae. 10.
8. Middle femora with one, middle and hind tibiae with no bristles; legs largely blackish; third abdominal segment with macrochaetae. var. **hecate**, n. var.
   Middle tibiae with one inner and one outer spinous bristle; legs largely yellow. 9.
9. Acrostichal setulae absent; third tergite with distinct macrochaetae. var. **violacea** Meigen.
   Acrostichal setulae present, though weak; bristles of legs stronger; third and fourth tergites with distinct macrochaetae. var. **similis** Macquart.

10. Larger, robust species, 5 mm. in length; middle tibiae with one inner and two or three outer bristles, hind tibiæ with two outer bristles, legs reddish; pectus and often the humeri and the first segment of the abdomen reddish; acrostichal and dorsocentral setulae strong; calypteres and fringe white. **pectoralis** Macquart.

Bristles of middle and hind tibiae usually not pronounced; thorax more slender; humeri and venter rarely yellow; calypteres more or less dusky. 11.

11. Less robust species, 2 to 4 mm. in length; both pairs of dorsocentral bristles strong; mesonotal and abdominal setulæ evident; wing-spot large, anterior crossvein sometimes at the apical third of discal cell, calypteres and fringe quite dark. (**signifera**, n. sp.) 12.

Mesonotal setulae minute or wanting, abdominal setulae sparse; the anterior dorsocentral bristles smaller than the posterior; stigmal spot small, anterior crossvein before apical third of the discal cell. 13.

12. Legs largely yellow. var. **signifera,** n. var.

Legs largely black. var. **curvitibia,** n. var.

13. Last section of fifth vein distinctly longer than posterior crossvein; legs yellow; veins yellowish to brown. 14.

Last section of fifth vein subequal to posterior crossvein; legs largely black; veins blackish; hairs of calypteres yellowish. **neocynipsea,** n. sp.

14. Front legs pale yellow, posterior legs darker; veins yellow; wing-spot very small, indefinite and rather rounded. **vicaria** Walker

Legs reddish; veins usually blackish; wing-spot larger, rather definitely quadrate in outline. **luteipes,** n. sp.

Sepsis pleuralis Coquillett

Coquillett, Jour. N. Y. Ent. Soc., XII. 35 (1904)

Recognizable among the unspotted wing forms by the wholly yellow pleuræ. Yellow, the front, upper part of the occiput, mesonotum except the lateral margins, middle of the metanotum and dorsum of the third, fourth and the base of the fifth segments of the abdomen, black, upper side of the scutellum, posterior margin of the second abdominal segment and the last three joints of the tarsi, brown; front polished, mesonotum subopaque, thinly brownish pruinose, metanotum polished and with a brassy tinge, dorsum of the abdomen opaque, somewhat scabrous and with a strong bluish tinge; under side of the front femora at two-thirds of the length bearing an outwardly projecting tooth; wings

hyaline, the base of the costal cell to slightly beyond the humeral crossvein, dark brown.

Length 4 mm. A single male from Southern Texas is known. The original description is given as the species is not among the material before us.

Sepsis discolor Bigot.

Bigot, Dipt. of Cuba, Sagra, 823 (1857)

scabra Loew, Wien. Ent. Monatschr., V. 42 (1861)

Head and thorax mostly reddish, the abdomen black; legs reddish yellow, the hind tibiæ brownish; wings hyaline except for the blackened base of the costal cell. Face, cheeks and antennæ yellow, front and occiput reddish brown, vibrissæ long, third antennal joint nearly twice as long as broad and half as long as the thin arista. Thorax reddish, the sides with a brown spot continuous with the mesopleura, lower pleuræ paler, the sternopleura with a distinct white-pruinose longitudinal line, two pairs of dorsocentral bristles, notal hairs sparse but evident. Abdomen opaque, scabrous, the hairs prominent, third segment with long marginal bristles, hypopygium reddish. Front femora of male with about six extensor bristles and with a single flexor bristle at the basal third, at the second third is a low conical tubercle tipped with a single short black spine; front tibiæ but slightly swollen and notched opposite the tubercle; median, inner and outer bristles and apical spurs of the middle tibiæ long. Halteres yellow, calypteres white; third vein ending at the apex of the wing, posterior crossvein as long as the middle section of the fourth vein and the ultimate section of the fifth.

Length 3.5 to 4 mm.

This insular species was described independently by both Bigot and Loew from Cuban material. Von Roeder reported it from Porto Rico. The preceding description was made from specimens furnished by Mr. C. W. Johnson from Cuba and Jamaica.

Sepsis ecalcarata Thomson

Thomson, Eugenies Resa, 588 (1868)

Head green-black, rounded; front flat, greenish, shining, glabrous; face very short, the middle brownish, antennal foveæ deep, diverging, attingent beneath the eyes; cheeks brownish, narrow; peristome oval, with some setulæ in front,

clypeus prominent, stipes of the proboscis brown; eyes large, frontal orbits anteriorly convergent; antennæ attaining the edge of the face, contiguous at the base, testaceous, third joint oval.

Near *cylindrica.* Front femora and tibiæ of the male excised; thorax shining æneous; base of posterior coxæ infuscated; fifth section of the costa scarcely one-half longer than the sixth; halteres whitish. Abdomen ovate, glabrous, æneous, nearly golden. Legs testaceous, hind tibiæ fuscous, middle ones with no outer spur, and hind ones without setæ; pectus and pleuræ æneous, metallic, above with a white-pruinose vitta.

Length 3 to 4 mm. (Translation from original description).

A single female alcoholic specimen received from Mr. C. W. Johnson and labeled Lower California is apparently this species but the body is a truer black. The notopleural suture is white-pruinose like the sternopleural vitta.

Sepsis hoplicnema, sp. nov.

Male. Vertex, occiput, front and cheeks shining black; postvertical bristles well developed; antennæ reddish, face yellow; anterior two pairs of oral bristles quite prominent. Notum black; one pair of dorsocentral bristles; entire pleura shining black. Front coxæ yellow with a few apical bristles; front femora brown, very much enlarged, increasing in size very abruptly on basal third, the under side bearing two tubercles with a marked excavation in between, the first tubercle bare, the second with claw-like projections, femora abruptly decreasing in size beyond the second tubercle and bearing a weak spine on their outer side near the base; front tibiæ yellow, the basal third forming two tubercles, the first with a fine pubescence, the second with from six to eight bristles, the under side of the apical two-fifths bearing rather stout pubescence; first two joints of the front tarsi yellow; middle femora without spines, black, yellow at the tip; middle tibiæ slender, black at the base, yellow at the tip, with one inner and no outer spine; hind tibiæ hairy, spineless, black; posterior tarsi with the first two joints whitish, the other three black. Abdomen hairy, without strong macrochætæ, black; claspers hairy, hypopygial valves with a slender projection on the inner side. Wings hyaline, without the subapical spot but slightly browned at the tip, base of costal cell blackened, veins blackish, anterior crossvein

slightly before the distal third of the discal cell, posterior crossvein about two-thirds as long as the last section of the fifth vein, fourth vein curving slightly toward the third at the tip, anal vein almost reaching the margin.

Length 4 mm. A single male from Hayti, received from Dr. Hough.

Sepsis armillata, sp. nov.

Occiput, vertex and front shining black; cheeks and face brownish, proboscis yellow; oral bristles weak, the anterior two pairs longer than the others; vertical bristles weak; antennæ small, yellow, the third joint oval. Notum shining black, bare, the acrostichals absent; entire pleura shining black, with a reddish tinge. Wings hyaline, wing-spot absent, veins light, anterior crossvein before the last third of the discal cell, posterior crossvein one-third as long as the last section of the fifth vein, fourth vein straight beyond the posterior crossvein and with a slight curve upward at the tip. Abdomen reddish black.

Male. Front coxæ armed with apical bristles, yellow; front enlarged to about three-fifths the distance from the base and then decreasing abruptly, the under side bearing a tubercle beset with a few bristles which extend to the base of the apical inner and outer sides of the tubercle, and a single spine at the middle; front tibiæ very narrow at the base, bent downward for one-third the distance and at the same time increasing in size, the under side bearing two weak tubercles, the first just before the basal third, bare, the second at the basal third and bearing a tuft of setulæ, yellow; front tarsi slender, yellow, excepting the apical two or three joints which are black; middle femora slender, black, yellow at the base, their tibiæ narrow, black except a small portion near the tip yellow, extreme tip black; middle tarsal joints slender, tarsi longer than the tibiæ, first two joints yellow, the others black; hind tibiæ entirely black, their tarsi the same as the middle pair; hind femora black the base yellow.

The female resembles the male except in the deformed femora.

Length 2 to 3 mm.

Two males and one female, Hayti; one male, Nassan, Bahamas (Johnson).

Sepsis furcata, sp. nov.

Occiput, vertex and front polished black; bristles of the head weak; antennæ yellow, the dorsal edge of the third joint blackish; face yellow, cheeks narrow, yellowish; anterior oral bristles longer than the others. Notum black, highly polished, acrostichal bristles entirely absent, one pair of dorsocentrals; pleuræ black with reddish reflection, polished throughout except a white-pruinose vitta above the sternopleura. Front legs entirely yellow excepting the black tips of the tarsi; front femora of male considerably enlarged to a bifid tubercle at the apical third and then deeply incised, bearing a weak bristle near the base and a short stiff spine on the outer apical side of the tubercle; front tibiæ of male twice incised on the under side, once weakly at the middle and again very deeply at the basal third; middle femora brown, yellow at the base and tip; basal half of the middle tibiæ with one outer and one inner spine; middle and hind legs brownish, excepting the yellow tibiæ. Abdomen bare, highly polished, the third, fourth and fifth segments with macrochætæ; hypopygium slightly hairy, the valves with a slender projection on the inner side. Wings hyaline, without a subapical spot, base slightly browned, veins brownish, anterior crossvein short, near the outer third of the discal cell, posterior crossvein half as long as the last section of the fifth vein, anal vein very short, almost absent.

Length 2 mm.

Four males and two females from Jamaica.

Sepsis insularis Williston.

Williston, Trans. Ent. Soc. Lond., 1896, 431, pl. xiv. f. 159 (1896)

Front, vertex and occiput black, polished; bristles of the head weak; antennæ yellow, the third joint slightly browned; face and cheeks brownish; proboscis brown; the fourth anterior oral bristle much longer than the others. Notum bare, black with a reddish tinge, polished; one pair of dorsocentral bristles, acrostichal setulæ absent; pleuræ entirely black except for a white-pruinose line on the upper portion of the sternopleura. Abdomen black, with a reddish tinge, polished, the second segment without macrochætæ; hypopygial valves with a slender projection on the inner side. Front legs yellowish excepting the black tips of the tarsi; front femora of the male armed on the under side with a stout spine and a bifid tubercle, bearing weak bristles, beyond which the femora are immediately narrowed; front tibiæ of the male nar-

rowed at the base but extended into a tubercle one-third the distance from the base, which bears a small bristle on its apical side; middle tibiæ with an inner and an outer bristle; middle and hind legs brown or blackish. Wings hyaline, browned at the base and with no subapical spot, veins brownish, anterior crossvein before the last third of the discal cell, posterior crossvein two-thirds as long as the last section of the fifth vein, anal vein quite distinct and almost reaching the margin.

Length 2 to 3 mm.

The species was originally described from St. Vincent. Coquillett (Proc. U. S. Nat. Mus., XXII. 259) records it from Porto Rico. Johnson has reported it from Jamaica and also from Florida. We have a series of some twenty specimens from Jamaica and Hayti and among the Johnson material there is an individual from Fort Myers, Florida.

Sepsis violacea Meigen

Meigen, Syst. Beschr. zwfl. Ins., V. 289 (1826)
Walker, Entom. Mag., I. 249 (1833)
Macquart, Hist. Nat. Dipt., II. 478 (1835)
Zetterstedt, Ins. Lapp., 749 (1838)
Staeger, Monogr. Seps., 26 (1844)
Zetterstedt, Dipt. Scand., VI. 2289 (1847)
Lucas, Explor. Scient. de l'Algerie, III. 498 (1849)
Schiner, Faun. Austr. Dipt., II. 179 (1864)
Rondani, Bull. Soc. Ent. Ital., VI. 8 (1874)
Howard, Proc. Wash. Acad. Sci., II. 586, fig. (1900)

Var. **similis** Macquart (not Brunetti, 1909)
Macquart, Dipt. Exot., Suppl., IV. 296 (269), pl. xxvii. fig, 11 (1851)

Var. **hecate**, var. nov.

Vertex and occiput black; front brownish; cheeks ferruginous; antennæ brownish to black, arista black; the anterior two pairs of oral bristles much stronger than the others; inner vertical bristles longer than the outer. Notum black; acrostichal setulæ absent, only one pair of dorsocentral bristles; pleuræ shining black except the pruinose sternopleura. Legs largely yellowish, front coxæ yellow, bearing an inner preapical bristle; front femora of male not much enlarged, increasing in size to about the middle and then gradually decreasing toward the tip, the underside bearing one stout spine and one or more smaller ones and two tubercles, each beset with a few small spines, the second tubercle from the

base lying in a lower plane than the first; front tibiæ of the male slightly arcuate, the inner side bearing a weak tubercle armed with a weak tuft of setulæ, yellow; front tarsal joints blackish; middle femora bearing **one** or rarely two setæ on the inner side at the middle, infuscated; middle tibiæ slender, with one inner and **one** or **two** outer setæ; hind tibiæ bearing **one** outer and no inner setæ; all the legs more or less yellow, with the posterior pairs darker. Abdomen shining black with a copper reflection, furnished with sparse minute setulæ, the first and second segments almost never with macrochætæ. Halteres yellow, calypteres brown. Wings hyaline, veins coarse and black, subapical spot small and somewhat circular in shape, anterior crossvein slightly before the outer third of the discal cell, posterior crossvein shorter than the last section of the fifth vein.

Length 3 to 4 mm.

This is apparently the commonest form of Sepsis. We have examined 300 specimens giving the following distribution. **Vermont**, Lynden (Melander); **Massachusetts**, Boston, Naushon Island, Woods Hole (Melander), New Bedford (Hough), Wellesley (Morse); **New York**, Cold Spring Harbor, Geneva (Melander); Ithaca (Univ. Ill. Coll.) **Pennsylvania**, Philadelphia, (Cresson, Johnson); **Virginia**, Mathais Point (Johnson); **New Jersey**, Atlantic City, Da Costa, Newark (Johnson); **Quebec**, Montreal (Chagnon); **Ontario**, Waubamic (Parish); **Florida**, St. Augustine (Johnson); **Illinois**, Chicago, Glen Ellyn, McHenry, Meredosia, Havana (Melander), Urbana (Osborn), Pulaski, Metropolis (Coll. Univ. Ill.); **Indiana**, Millers (Melander); **Texas**, Austin (Melander); **Kansas**, Wathene (Cresson), Lawrence (Aldrich); **Montana**, Saltese, Glacier Park (Melander); **Wyoming**, Sheridan (Metz); **New Mexico**, Highrolls, Alamogordo (Viereck); **Idaho**, Bovill, Chatcolet, Collins, Priest Lake (Melander), Moscow (Aldrich, Melander); **Washington**, Pullman, Rock Lake, Clarkston, Almota, Palouse, Deer Park, Kettle Falls, Kamiac Butte, Kennewick, Yakima, Oroville, Chehalis, Bellingham, Lynden, Nooksack, Quilcene, Chimacum, Olga (Melander), Mt. Rainier, Mt. Constitution, Friday Harbor (Aldrich), Grand Coulee (Jenne); **British Columbia**, Nelson, Keremeos (Melander), Vancouver Island (Livingston); **Alaska**, Sitka (Shaw); **Oregon**, Newport (Aldrich); **California**, Berkeley (Cresson, Melander), Clare-

mont (Metz), Palo Alto (Aldrich, Melander), St. Helena (Fuchs), Pacific Grove, Redwood City (Aldrich). Johnson has recorded the species as abundant in Bermuda.

Sepsis violacea var. similis Macquart

The distinctive characters whereby this variety differs from *violacea*, sensu stricto, are merely as follows. All these characters are variable so that the two forms intergrade with each other. Acrostichal setulæ evident. Legs yellowish, middle femora with two strong setæ at the middle of the under side; middle tibiæ with one inner and three or two outer setæ; hind tibiæ with two outer setæ.

Over one hundred specimens of this form are before us taken at the following localities. **Massachusetts**, New Bedford (Hough), Woods Hole, Greenfield (Melander); **Pennsylvania**, Philadelphia (Cresson); **West Virginia**, Fairmount (Cresson); **Illinois**, Chicago (Melander,) White Heath (Coll. Univ. Ill.) Algonquin (Nason, det. as *vicaria* by Coquillett); **Indiana**, LaFayette (Melander); **Texas**, Austin (Melander); **Wyoming**, Sheridan (Metz); **New Mexico**, Highrolls, Beulah, Top of Las Vegas Range (Acad. Sci. Phil.); **Idaho**, Collins, Troy, Chatcolet (Melander); **Washington**, Pullman (Melander, Yothers), Clarkston, Wawawai, Palouse, Winlock, Woodland, Bellingham, Mt. Constitution (Melander); **Oregon**, Oregon City (Melander); **British Columbia**, Nelson, Keremeos (Melander), Vancouver Island (Livingston); **California**, Berkeley, Yosemite Valley (Cresson), Stanford (Melander).

Sepsis violacea, var. hecate, var. nov.

Acrostichal setulæ present but weak. Legs largely blackish, the middle femora with one reduced bristle on the inner side at the middle, middle tibiæ with one inner and two outer setæ, hind tibiæ with one reduced outer seta.

Fifty-five specimens of the collection show the reduced leg bristles and darkened legs of this variation. They come from the following localities: **Massachusetts**, Greenfield (Melander); **Illinois**, White Heath (Coll. Univ. Ill.); **Colorado**, Marshall Pass (Aldrich); **Montana**, Nigger Hills (Mann);

Idaho, Troy (Mann), Collins, Chatcolet, Potlatch (Melander); **Washington**, Pullman, Clarkston, Palouse, Wawawai, Rock Lake, Kettle Falls, Winlock, Woodland, Mt. Constitution (Melander); **British Columbia**, Keremeos (Melander); **Oregon**, Portland (Melander); **California**, Berkeley, (Cresson).

Sepsis pectoralis, Macquart

Macquart, Hist. Nat. Dipt., II. 478 (1835).
Meigen, Syst. Beschr. zwfl. Ins., VII. 349 (1838).
Rondani, Bull. Soc. Ent. Ital., VI. 9 (1874).
Becker, Mitt. Zool. Mus. Berlin, IV. 146 (1908)

Antennæ, cheeks and front reddish yellow; vertex and upper occiput black; the anterior four pairs of oral bristles much longer than the others. Humeri and pleuræ reddish to a variable extent, notum black; acrostichal setulæ strong, always two pairs of dorsocentral bristles; legs yellow, the posterior tibiæ sometimes darkened. Front femora of the male greatly enlarged on the basal two-thirds, the under side bearing one or two abnormally stout spines before the middle and a carina-like tubercle just beyond the middle beset with seven closely set spines, the third one of which is strong, while between the tubercle and the apex occur five minor bristles; front tibiæ robust, decidedly arcuate, the flexor side twice emarginate and bearing a setulose tubercle toward the base between the emarginations; middle femora with one or two stout setæ on the middle of the anterior side; middle tibiæ with one inner and two outer setæ. First segment and the ventral side of the abdomen typically yellow, abdominal setulæ distinct, all the segments with lateral subapical bristles especially strong on the second and third segments; hypopygium rather small and narrow, with a stronger bristle on each side, the end-processes long, slender and parallel or slightly crossing. Wings with square stigmal spot not sharply outlined, veins yellow, anterior crossvein before the distal third of the discal cell, posterior crossvein as long as the last section of the fifth vein.

Length 4 to 5 mm.

This species exhibits a wide range in color. Typically the pleuræ and base and hypopygium of the abdomen are yellow, the light color extending on the notum at the humeri. Such coloration is possessed by the European material furnished by Th. Becker and also by Illinois specimens taken by the senior writer. There is every gradation to the black-

ness characteristic of Pacific Coast material, though the pectus and hypopygium retain a reddish tinge in the majority of specimens. Females have a greater tendency to darkness and are indistinguishable from females of the European *punctum* Fabricius. The latter species is supposed to occur in America and specimens so identified have been distributed by Dr. Hough. We have seen no American specimens that agree with the European *punctum* furnished by Messrs. Th. Becker and G. Strobl. The femoral tubercle of *punctum* is broken into three long apophyses, while that of *pectoralis* presents an even triangular outline. In Dr. Aldrich's collection a specimen of the present species was labeled *punctum;* in the collection of the Washington State College *luteipes* was so determined by Dr. Hough; while the senior writer has received *signifera* from Dr. Hough under the name of *punctum*. Dr. Hough identified the present species as *cynipsea*.

A large, easily recognized and common species. In its parallel hypopygial prongs, type of femoral structure and pale calyptral cilia it approaches *neocynipsea*, but differs in that the prongs are shorter and stronger, the femora much stouter, the calypteres paler. It is the only species with the calypteres entirely pale. Over 200 specimens from the following widely separated localities occur in the collection. **Massachusetts**, Woods Hole, Forest Hills, Greenfield (Melander), New Bedford (Hough); **New Hampshire**, Durham (Johnson); **Vermont**, Lynden (Melander); **New York**, Cold Spring Harbor (Melander); **Ontario**, Ottawa (Johnson), Coniston (Parish); **Pennsylvania**, Delaware Co. (Cresson); **Illinois**, Algonquin (Nason), Elliott, Homer, Muncie, Urbana (Coll. Univ. Ill.), Chicago, McHenry, (Melander); **South Dakota**, Brookings (Aldrich); **New Mexico**, Cloudcroft, Alamogordo, Highrolls (Viereck); **Wyoming**, Sheridan (Metz); **Idaho**, Troy (Mann), Houser (Yothers), Collins, Moscow Mt. (Melander); **Washington**, Pullman (Doane, Mann, Melander, Yothers), Clarkston, Almota, Prosser, Wenatchee, Kennewick, Nooksack, Mt. Constitution (Melander), Deer Park, Chehalis (Yothers), Rock Lake (Snodgrass). The species

has previously been known from France, Italy and the Canary Islands.

Sepsis pyrrhosoma, sp. nov.

A rather reddish species. Vertex and occiput brown, front and lower occiput reddish; the inner vertical bristle as long as the third antennal joint and about twice as long as the outer bristle; ocellar bristles reaching half way to the antennæ; antennæ slightly brownish, the third joint considerably longer than deep; oral bristles weak except the anterior two pairs; proboscis yellow, clypeus black (♂) or yellow (♀); face and cheeks yellowish. Notum piceous brown, subshining, largely reddish along the sides; two pairs of dorsocentral bristles, acrostichal setulæ very small; scutellum and pleuræ reddish, sternopleura entirely pruinose. Legs yellow, front femora of the male very little enlarged, the under side bearing one long spine at the middle and a slight tubercle armed with five uniform shorter spines; their tibiæ slightly decreasing in size toward the tip and bearing a very weak setulose tubercle on the under side near the base; middle femora with two inner and the middle tibiæ with one inner and one outer setæ; hind tibiæ without the setæ. Abdomen with cupreous tinge, the base, apex and venter reddish, the remainder black; clothed with relatively long and abundant setulæ (♂), the first four segments (♂) with lateral macrochætæ, the female with a small bristle only on the first segment; hypopygial valves with the slender end-projections angulate and decussating. Wings hyaline, with a small triangular spot at the tip of the second vein and with the base blackish, veins brown, the anterior crossvein before the apical third of the discal cell, the posterior crossvein two-thirds as long as the last section of the fifth vein; calypteres brown; halteres yellow though brown at the base.

Length 3 mm. One male, Lafayette, Indiana (Melander) and one female, Philadelphia, Pennsylvania (Johnson).

Sepsis vicaria Walker

Walker, List Dipt. Brit. Mus., IV. 998 (1849)

Face yellow; vertex, occiput, front and cheeks shining black; antennæ brownish, the arista black. Notum black, acrostichals in two rows and weak, two pairs of dorsocentral bristles; pleuræ black, sternopleura entirely pruinose. Front femora of male not much enlarged, gradually increasing in size to about the middle, the under side bearing a single

spine and a tubercle armed with three or four small setulæ; front tibiæ of male straight, gradually increasing in size toward the tip, the under side bearing a weak tubercle armed with stiff setulæ; front legs yellow; middle femora with one or rarely two setæ at the middle of the anterior side; middle tibiæ with one inner and no outer seta; posterior femora darker except the yellowish base and apex. Abdomen with short hairs, shining black with a purple reflection. Wings hyaline, subapical spot rather small, irregular in outline; posterior crossvein half as long as the last section of the fifth vein.

Length 2 to 3 mm.

This species was originally described from Florida. Johnson has since reported it from the same state. It may be that the present species is not the same as Walker's but pending further information from the type Walker's name may be used here. One hundred specimens of this rather small and delicate species are before us from the following localities:

Bermuda (Jones); **Massachusetts**, Greenfield, Woods Hole (Melander); **Pennsylvania**, Swarthmore (Cresson); **New Jersey**, Buena Vista (Johnson); **Illinois**, Chicago (Melander); **Texas**, Austin (Melander); **New Mexico**, Highrolls, Cloudcroft, Alamogordo (Rehn, Viereck); **Montana**, Glacier Park, Flathead Lake (Melander); **Wyoming**, Sheridan (Metz); **Idaho**, Collins, Moscow Mt., Potlatch (Melander); **Washington**, Pullman, Almota, Monroe, Chehalis, Quilcene, Bellingham, Nooksack, Mt. Constitution (Melander); **Oregon**, Portland (Melander); **California**, Berkeley (Fuchs); **British Columbia**, Nelson (Melander); **Alaska**, Douglas (Jenne).

Sepsis signifera, sp. nov.

Upper part of the front, vertex and occiput black; lower part of the front, face and cheeks sometimes yellowish; antennæ brownish to black, the arista black; inner vertical bristle strong, longer than the outer; two or three anterior oral bristles much longer than the others; proboscis yellowish, clypeus black. Notum black, somewhat subshining with a double row of acrostichal setulæ, the dorsocentral rows and an irregular row along the sides of the notum often quite pronounced; two pairs of strong dorsocentral bristles; sternopleuræ entirely pruinose. Front coxæ yellow, front

femora yellow to black, of the male enlarged for two-thirds the distance from the base, beyond which they are strongly and abruptly excised, the under side bearing one or two rather strong spines near the middle and a pronounced tubercle which is armed with one or two spines and a group of setulæ; front tibiæ usually yellow, of the male stout, deeply biarcuate on the inner side and setulose toward the base, the outer side decidedly sinuate; tarsi black; posterior legs brownish to black, the tibiæ and tarsi especially dark; middle femora with one strong and a few weak setæ on the inner sides, their tibiæ with several inner and outer setæ; hind tibiæ with one inner and two outer setæ. Abdomen shining black, pubescent, the second, third and fourth segments and the hypopygium with lateral macrochætæ, the hairs of the hypopygium and abdomen conspicuous, the end-process of the hypopygial valves short, decussate and projecting almost at right angles. Calypteres and root of halteres black. Wings hyaline or somewhat infumated, with a large, irregularly oblong stigmal spot, costa and third vein black, the other veins sometimes brownish; anterior crossvein at or near the last third of the discal cell; posterior crossvein slightly shorter than the last section of the fifth vein.

Length 3 to 4 mm.

Type from Chester Co., Pennsylvania, collected by J. C. Bradley, June 4, 1902, and belonging to the senior writer. Thirty-five paratypes from **Massachusetts**, New Bedford (Hough, determined as *punctum*), Woods Hole (Melander), Auburndale (Johnson); **New York**, Cold Spring Harbor (Melander); **New Hampshire**, Hanover (Johnson); **Illinois**, Algonquin (Nason); **New Mexico**, Alamogordo, Cloudcroft (Viereck, Rehn); **Idaho**, Moscow, on carrot flowers (Aldrich); **Washington**, Clarkston, Kamiac Butte, Bellingham, Mt. Constitution (Melander), Grand Coulee (Jenne); **British Columbia**, Nelson (Melander).

The typical form presents these characters: legs mainly yellowish, the front femora of the male with two spines before the tubercle; mesonotal setulæ strong; veins brownish, the anterior crossvein often at the apical third of the discal cell.

Sepsis signifera, var. curvitibia, var. nov.

A large series of specimens is constant in the following variations from the characters of *signifera* last mentioned. Legs nearly or quite black except the front coxæ, the front femora of the male with a single spine before the tubercle; mesonotal setulæ not remarkably strong, the anterior dorsocentral bristle always considerably shorter than the posterior; wings somewhat infumated, veins black, the anterior crossvein never at the apical third of the discal cell; size smaller, measuring 2 to 3 mm.

Type ♂, Chimacum, Washington, August 23, 1910 (Melander); sixty-eight paratypes from **Massachusetts**, Boston, Greenfield (Melander), New Bedford (Hough); **Vermont**, Lynden (Melander), Norwich (Johnson); **Maine**, Eastport (Johnson); **Connecticut**, Yalesville, West Haven (Viereck); **New York**, Cold Spring Harbor (Melander), Buffalo (VanDuzee); **Pennsylvania**, Chester Co. (Bradley); **Illinois**, Algonquin (Nason), Mahomet (Coll. Univ. Ill.); **Idaho**, Moscow (Aldrich); **Washington**, Pullman (Yothers, Melander), Grand Coulee (Jenne), Wawawai, Oroville, Washougal, Chehalis, Dungeness, Olga (Melander); **British Columbia**, Nelson (Melander.

Sepsis neocynipsea, sp. nov.

Front, vertex and face black, cheeks brown; antennæ yellow, the arista black; oral bristles rather prominent. Notum black, two pairs of dorsocentral bristles, acrostichal setulæ evident; sternopleuræ entirely pruinose. Front coxæ blackish, front femora black, in the male enlarged to two-thirds the distance from the base, the under side bearing a single spine at the middle and a tubercle beset with five stout bristles, beyond which is another small stout bristle and a row of two or three hairs; front tibiæ almost straight, the under side slightly arcuate, near the base bearing a small tubercle beset with a few bristles; posterior femora black; middle tibiæ with one inner and two outer setæ; all the legs usually black, rarely reddish to yellow. Abdomen shining black, the second, third and fourth segments with macrochætæ; hypopygial prongs long, slender and parallel. Wings hyaline, with a rectangular almost square subapical spot, veins black, anterior crossvein before

the last third of the discal cell, posterior crossvein shorter than the last section of the fifth vein.

Length about 3 mm.

This is probably the species recorded under the name of *cynipsea* L. by Coquillett (Proc. Davenport Acad. Nat. Sci., VII. 155) as occurring in New Mexico. Over 300 pinned specimens are before us from the following places: **Massachusetts**, Cohasset (Bryant), New Bedford (Hough), Woods Hole, Greenfield, Boston (Melander); **Vermont**, Lynden (Melander); **New Hampshire**, Glen House (Johnson); **Pennsylvania**, Lansdale, Philadelphia (Cresson); **District of Columbia**, Washington (Melander); **Ontario**, Waubamic (Parish); **Illinois**, Chicago, Havana (Melander), Muncie, Homer (Coll. Univ. Ill); **Kansas**, McPherson (Knaus); **New Mexico**, Alamogordo, Highrolls, Cloudcroft (Viereck, Rehn); **Idaho**, Avon, Bovill, Potlatch (Melander), Moscow Mt. (Melander, Yothers), Houser (Yothers); **Washington**, Pullman (Melander, Yothers), Almota, Clarkston, Wawawai, Palouse, Spokane, Kettle Falls, Oroville, Kennewick, Wenatchee, Stevenson, Chehalis, Chimacum, Washougal, Mt. Constitution (Melander), Rock Lake (Snodgrass); **Oregon**, Hood River (Melander); **California**, Berkeley (Cresson), Stanford, Muir Woods (Melander); **Alaska**, Douglas (Jenne).

Sepsis luteipes, sp. nov.

flavimana Schiner (not Meigen, 1826) Faun. Austr. Dipt., II. 180 (1864)

Head with the occiput, vertex, front and cheeks black; face and antennæ brownish, arista black; oral hairs long, three or four pairs of vibrissæ; ocellar bristles reaching three-fifths the distance to the antennæ. Notum only slightly shining, black, two pairs of dorsocentrals, acrostichal setulæ weak. Front femora of male moderately enlarged for about two-thirds the distance from the base and then deeply incised, the under side bearing a prominent spine at the middle and a tubercle beset with four rather stout spines, distal to the tubercle is a pronounced tooth directed toward the knee; front tibiæ of male slightly arcuate, the under side bearing a very weak setulose tubercle near the knee; middle femora with one or rarely two setæ on the front side near the center; middle tibiæ with one outer and one inner

setæ; all the legs usually yellow. Abdomen slender, bronzed black, the setulæ sparse, no macrochætæ on the first and second segments of the male or on any of the segments of the female; end-process of hypopygial valves subterminal, triangular, decussating. Calypteres with dusky margin and fringe; root of halteres brown. Wings hyaline, the black subapical spot rather indefinite in outline, veins brownish, the anterior crossvein located before the apical third of the discal cell, posterior crossvein shorter than the last section of the fifth vein.

Length about 3 mm.

This is the species known in Europe as *flavimana* Schiner, nec Meigen. Of the American species it is related to *violacea* as shown by the dentate front femora and reduced chætotaxy of the male abdomen. It differs, however, in having two dorsocentrals, but a single middle spine on the front femora and longer, less angulate, subterminal, hypopygial prongs. American specimens show no evident variation from European material secured through Th. Becker from Dalmatia and Schlesia. The original *flavimana* of Meigen as diagnosed by Frey is a distinct species with doubly excised front tibiæ and with closely setose nondentate femoral tubercle.

Thirty-five specimens from Europe, Dalmatia and Schlesia (Becker); **Illinois**, Chicago (Melander); **New Mexico**, Alamogordo (Viereck, Rehn); **Wyoming**, Sheridan (Metz); **Idaho**, Moscow (Melander), Troy (Mann); **Washington**, Pullman, Wawawai, Palouse, Deer Park, Kettle Falls, Stevenson, Winlock, Chehalis, Bellingham, Mt. Constitution (Melander), Friday Harbor (Aldrich); **California**, Muir Woods (Melander).

Sepsis fulvicoxalis Bigot

Bigot, Annales Soc. Ent. Fr., 1886, 390 (1886) *Piophila*

Male. Shining black; antennæ deep brown; face and cheeks yellowish, front shining black; halteres whitish; pleuræ gray; coxæ and legs yellow, the femora and posterior tibiæ brownish exteriorly, all the tarsi brown with the base of the segments yellowish; wings hyaline, a subapical blackish spot.

Female. Similar to the male, antennæ lighter, femora

and tibiæ less brown. Tip of hind tibiæ with a black ring. Ovipositor reddish.

Length 4 mm. California. Occurring possibly in Cuba.

This species was originally described as *Piophila* and was placed in Aldrich's Catalog in *Nemopoda*. The subapical spot of the wings indicates a *Sepsis*. The description translated above is very vague and the distribution of the species from California to the West Indies is problematical. The species must remain uncertain until the type is again studied.

Genus **SEPSIDIMORPHA** Frey

Frey, Deut. Ent. Zts., 1908, 584 (1908).

This genus was erected by Richard Frey in his important paper Ueber die in Finnland gefundenen Arten des Formenkreises der Gattung *Sepsis* Fall. He characterized it as being very similar to Sepsis in having two pairs of verticals, two pairs of dorsocentrals, the wings with a subapical spot and the lower part of the pleuræ white-pruinose, but as distinguishable by the simple front femora and tibiæ of the male and by the absence of abdominal macrochætæ. As the females present no tangible characters the validity of the genus is lessened, although it may be recalled that in this family almost all the genera are defined best by the male characters. The genus was founded on the small European species *Sepsis pilipes* Loew. Loew's description states further that the hairs at the termination of the abdomen are longer and more abundant than usual. Since Wulp two years before Loew had described another species as *Sepsis pilipes* Hendel has changed Loew's name to *S. Loewi*. As this change is unnecessary if the species is not a *Sepsis* it is not here adopted for we disapprove of the recommendation followed by some biologists of "once a synonym always a synonym."

The senior author has three specimens which agree with the preceding description and which may be considered as congeneric with the European form, although they differ in that the legs are not remarkably slender, the middle femora are not pilose and the oral hairs are not reduced. At first sight these specimens were taken to be females of *Sepsis* with

the genitalia abnormally expanded. A closer study shows them to have male sex organs quite different from those of *Sepsis.* The second segment of the abdomen is much longer than usual, the third segment somewhat scabrous and the remaining segments very short but forming a greatly expanded truncate ending to the abdomen. This part of the abdomen is furnished with longer hairs. The hamate projections from the valves of the hypopygium extend at right angles and are broad, flat and clavate, the tip capped with close-set microscopic setulæ. The chætotaxy includes one humeral, two notopleural, one supra-alar bristles, no propleural setæ, postverticals strong. The front femora have short but outstanding setæ beneath, but are not tuberculate; an easy character for distinguishing the males from *Sepsis.*

TABLE OF THE VARIETIES OF SEPSIDIMORPHA.

1. Discal cell relatively short, the sections of the fifth vein proportioned 2 : 1, wing-spot elliptical, veins black; scutellum 4-setose; legs mostly black; arista less than twice as long as the third antennal joint. **secunda,** n. sp. and var.
   Discal cell longer, the sections of the fifth vein 3 : 1, wing-spot oblong, veins brown; lateral scutellar bristles short. 2.
2. Legs mostly black; lower part of fourth tergite not remarkably expanded. var. **piceipes,** n. var.
   Legs mostly yellow, lower portion of fourth tergite greatly expanded. var. **brunnipes,** n. var.

Sepsidimorpha secunda, sp. nov.

Male. Body black, legs mostly black. Head with the face, cheeks and lower part of the front brown; antennæ very short, the last joint orbicular, the thin bare black arista scarcely twice as long as the third antennal joint; oral fringe of hairs prominent. Mesonotum finely aciculate, four strong scutellar bristles, mesopleural subalar bristle strong, metanotum polished. Abdomen narrow, strongly constricted at the second segment, polished violaceous, its hairs sparse but long, hypopygium small. Front coxæ, base of the front tibiæ and apex of the hind femora yellow, trochanters brown, under side of the front femora with about eight uniform projecting short setæ. Halteres pale yellow, their stalk

brown; calypteres brown. Wing-spot large, elliptical, bisected by the second vein, veins black, anterior crossvein at three-fifths the discal cell, sections of the fifth vein proportioned 2 : 1, anal vein reaching less than half way to the margin.

Length 2.5 mm.

Holotype: Union Flat, near Pullman, Washington, June 16, 1916 (Melander). Owing to the limited material the range of variation within the group is unknown and the following forms are hence considered as varieties rather than as distinct species.

Sepsidimorpha secunda, var. **piceipes**, var. nov.

Front black, minutely scrobiculate. Lateral scutellar and mesopleural bristles small. Abdominal hairs fine and sparse except toward the tip. Front coxæ, anterior surface of the front femora, entire front tibiæ, middle knees and apex of the middle tibiæ brownish yellow, remainder of legs piceous black. Wing-spot large, oblong, reaching further behind the second vein than in *secunda*, veins brownish, the sections of the fifth vein proportioned 3 : 1.

Length 2.5 mm.

A single male, Chatcolet, Idaho, August, 1915, (Melander).

Sepsidimorpha secunda, var. **brunnipes**, var. nov.

Lower part of front becoming brown. Lateral scutellar bristles minute, mesopleural bristle strong. Abdominal hairs short, sides of the fourth tergite greatly expanded below so as to give a club-like termination to the abdomen. Legs entirely brown. Wing-spot oblong, extending almost to the third vein, veins brownish, the sections of the fifth vein proportioned 3 : 1.

Length 2.5 mm.

A single male, among some grass sweepings obtained from J. Chester Bradley, Chester Co., Pennsylvania, 1902.

Genus **MEROPLIUS** Rondani

Rondani, Bull. Soc. Ent. Ital., VI. 175 (1874)
Frey, Deut. Ent. Zts., 1908, 585 (1908)

Head spherical, occiput smooth, two pairs of vertical bristles, one pair of fronto-orbitals, oral bristles hair-like, a single vibrissa developed, cheeks narrow, nearly horizontal.

Mesonotum aciculate, not polished, discal setulæ in three rows, one each of humeral, dorsocentral, supra-alar and post-alar bristles, two notopleural, two scutellar bristles; sternopleuræ partly shining. Front femora of the male slightly deformed, the under side bearing a stout blunt thorn and an adjacent pointed thorn-like bristle, front tibiæ of the male bent, compressed and posteriorly explanate at the middle; front femora of the female with a flexor bristle. Abdomen constricted between the first and second segments, devoid of macrochætæ and with very sparse hairs, last ventral segment of the male with two small weakly hairy processes which are usually retracted from view; hypopygium robust, the end-processes of the valves abruptly extending at right angles to the line of the hypopygium, curving and crossing each other. Wings entirely hyaline, without the subapical stigma or basal blackening, anterior crossvein beyond the middle of the discal cell.

But a single species is included in this genus, the following:

Meroplius stercorarius Desvoidy

Desvoidy, Myodaires, 745 (1830) *Nemopoda*
Walker, Ent. Mag., I. 251 (1833) *Nemopoda*
Macquart, Hist. Nat. Ins. Dipt., II. 482 (1835) *Nemopoda*
Meigen, Syst. Beschr. Zwfl. Ins., VII. 351 (1838) *Nemopoda*
Zetterstedt, Dipt. Scand., VI. 2298 (1847) *Sepsis*
Schiner, Faun. Austr. Dipt., II. 181 (1864) *Nemopoda*
Rondani, Bull. Soc. Ent. Ital., VI. 176 (1874)

minutus Wiedemann, Auss. Zweifl. Ins., II. 468 (1830) *Sepsis*
Howard, Proc. Wash. Acad. Sci., II. 587, fig. (1900) *Nemopoda*

rufipes Meigen, Syst. Beschr. Zweifl. Ins., VII. 349, ♂ only (1838) *Sepsis*
Becker, Zts. Hym. Dipt., II. 230 (1902) *Nemopoda*

Male. Head, thorax and abdomen black, the last with a slight violaceous reflection, legs largely yellow. Occiput subshining, bare except for the cluster of cervical setulæ, front grooved, ocellar bristles reaching two-thirds the distance to the antennæ, cheeks one-tenth the eye-height; antennæ dark brown; proboscis yellowish. Mesonotum not shining, aciculate, including the scutellum olivaceous black,

bristles strong, setulæ sparse and weak, pleurae shining, the sternopleura partially pruinose. Front coxæ with two or three apical bristles, yellow; front femora scarcely enlarged, the under side bearing two stout thorn-like spines just beyond the middle, the proximal one pointed, the other cylindrical and blunt, both arising from slight swellings, two long slender flexor bristles present toward the base of the femur; front tibiæ arched inwardly on the outer side making a pronounced curve, strongly compressed along the middle and with a thin compressed tubercle on the flexor edge, beyond which the tibia increases in size toward the tip, a single strong flexor bristle at the basal third; middle femora without bristles, their tibiæ with one flexor bristle at the apical third; hind legs without bristles or deformity. Hypopygium and apex of abdomen with a few hairs.

Female. A small spinous bristle slightly beyond the middle of the flexor side of the front femora; front tibiæ straighter and without a tubercle.

Length about 4 mm.

Robineau-Desvoidy and Wiedemann each described this species in 1830, the former from Europe, the latter from America. Since Desvoidy's *stercoraria* has been repeatedly published and is widely known we prefer to adopt it for this species. This coprophagous insect is widely distributed through Europe and North America and is recorded also from Argentina. It has been reared from human fæces both in Europe and America. Rondani designated *stercorarius* as the type of his genus *Meroplius*.

We have over seventy specimens from the following places: **Massachusetts**, Woods Hole, Greenfield (Melander), New Bedford (Hough); **Connecticut**, Putnam, New Haven (Viereck), Branford (Winkley); **Vermont**, Norwich (Johnson); **New Hampshire**, Durham (Johnson); **New York**, Cold Spring Harbor (Melander); **New Jersey**, Riverton, Newark, Woodbury (Johnson); **Pennsylvania**, Swarthmore, Lansdale, Allegheny (Cresson), Philadelphia (Johnson); **Ontario**, London (Hough); **Illinois**, Algonquin (Nason), Dubois, in cellar (Coll. Univ. Ill.); **Alabama** (Baker); **Kansas**, Lawrence (Aldrich); **Colorado** (Baker); **Washington**, Lynden (Melander); **British Columbia**, Nelson (Melander). Johnson has reported it from several places in Florida. The species is recorded by

Dr. Howard from the District of Columbia and Virginia as associated with human excrement.

Genus **NEMOPODA** Desvoidy

Desvoidy, Myodaires, 743 (1830).
Schiner, Faun. Austr. Dipt., II. 180 (1864).
Rondani, Bull. Soc. Ent. Ital., VI. 178 (1874)
Frey, Deut. Ent. Zts., 1908, 585 (1908)

Head spherical, face carinate, cheeks narrow, not broader behind; antennæ small, the third joint short, oval, two pairs of vertical bristles, the outer ones small; orbital bristles very weak or entirely absent; oral bristles hair-like, the vibrissæ not developed. Mesonotum with scattered sparse minute bristles; one pair of dorsocentral bristles, one pair of scutellars, one supra-alar, one humeral, two notopleurals. Front femora of the male not deformed but with spinous bristles along the lower side. Abdomen slightly constricted before the second segment, broader in the female, without macrochætæ; genitalia of the male prominent, furnished with numerous hairs, forcipate, with thick end-processes, the last ventral segment with short lateral processes.

Genotype: *N. cylindrica* Fabr. (as *putris)* by Westwood's designation (Introd. Class. Ins., II. 148, 1840).

KEY TO THE NORTH AMERICAN SPECIES OF NEMOPODA

1. Humeri and the sides of the thorax more or less testaceous. , **cylindrica** Fabricius.
   Body entirely black. 2.
2. Front blue-black, abdomen brassy, legs yellowish, the hind femora brownish, thorax dull. **coerulifrons** Macquart.
   Body not metallic, thorax more or less shining, legs darker. 3.
3. Front marked with yellow above the base of the antennae, pleurae and legs cinereous, halteres and calypteres whitish, wings gray. **obscuripennis** Bigot
   Front not marked. 4.
4. Head black, antennae and halteres brown, legs mostly black. **aterrima** Bigot.

Face and cheeks, antennae and halteres yellowish, legs largely brownish. **cubensis** Bigot

Nemopoda cylindrica Fabricius

Fabricius, Entom. Syst., IV. 336 (1774) *Musca;* Syst. Antl., 263 (1805) *Calobata*

Meigen, Syst. Beschr. zwfl. Ins., V. 290 (1826) *Sepsis*

Walker, Ent. Mag., I. 251 (1833)

Macquart, Hist. Nat. Ins. Dipt., II.. 480 (1835) *Sepsis*

Bouche, Naturgesch. Insekt., 95, pl. vi. f. 8, 9 (1837) *Sepsis*

Staeger, Sepsid., Kröjer's Tidskr., I. 33 (1844) *Sepsis*

Zetterstedt, Dipt. Scand., VI. 2301 (1847) *Sepsis*

Lucas, Explor Scient. de l'Algerie, III. 499 (1849)

Walker, Ins. Brit., II. 211 (1853)

Schiner, Faun. Austr. Dipt., II. 181 (1864)

Rondani, Bull. Soc. Ent. Ital., VI. 178 (1874)

Brauer, Zwfl. Kais. Mus. Wien, 84 (1883)

Wulp, Tijd. Ent., XXVI. 51 (1883) oc. in America

nitidula Fallen, Dipt. Suec. Ortalid., 21 (1820) *Sepsis*

putris Desvoidy, Myodaires, 744 (1830)

Vertex, occiput, front and cheeks black; face sericeous; outer vertical bristles feeble, the inner strongly developed; postvertical bristles of moderate size; antennæ reddish. Notum covered with rows of fine short hairs, dull black, the scutellum velvety, humeri and pteropleuræ reddish, sternopleuræ white-pruinose above, otherwise dull black. Front coxæ armed with apical bristles, yellow; front femora of the male not enlarged, the flexor side bearing two long spines and six or more short spines, the inner side near the base with one rather long flexor bristle; front tibiæ slender, straight, as long as the femur, the under side bearing rows of very fine, closely set spinules for two-thirds the distance from the base; tarsal joints pubescent, the first joint sometimes yellow, the others black; middle femora slender, without bristles, base yellow, the remainder black; middle tibiæ slender, black, bearing a number of small apical bristles and one flexor bristle; tarsal joints black; inner side of hind trochanters of male with two downward-directed black thorn-like spines; hind femora armed with three stout and two smaller bristles on the inner side, black except the extremities; hind tibiæ and tarsi pubescent, a few outstanding hairs toward the tip of the tibiæ, black. Abdomen petiolate, covered with fine pubescence, black, hypopygium prominent, claspers stout, the last ventral with several extensile hook-like processes. Wings lightly infumated toward the tip,

veins coarse, black or brownish, anterior crossvein before the outer third of the discal cell, posterior crossvein equal to the last section of the fifth vein.

Female differs from the male in that the front femur does not bear the long spines but has a comb-like row of short stout spines on the apical third of the under side. The spines of the hind femora are also absent. Apex of the abdomen normal.

Length 3.5 to 5 mm.

This species has been reared from human excrement. It is not uncommon both in Europe and the Eastern part of America. We have 100 specimens in the collection before us from the following localities: **Maine**, East Port, Fort Kent (Johnson); **Massachusetts**, Boston, Greenfield, Woods Hole (Melander), Weston (Johnson), New Bedford (Hough); **New Hampshire**, Glen House (Johnson); **Vermont**, Dummerston (Johnson); **Rhode Island**, Newport (Johnson); **Connecticut**, Putman (Viereck), Darien (Johnson); **New York**, Long Island, Geneva (Melander), Niagara Falls (Johnson), Ithaca (Coll. Univ. Ill.); **New Jersey**, W. Orange (Weidt), Dover, (Johnson); **Pennsylvania**, Philadelphia (Cresson, Johnson); **Quebec**, Montreal (Chagnon); **Ontario**, Ottawa (Beaulieu), Conniston (Parish).

Nemopoda aterrima Bigot

Bigot, Annales Soc. Ent. Fr., 1886, 390 (1886)

Female. Shining black; antennæ and halteres tinged with brown; the knees, the base of the tibiæ and the front tarsi largely yellowish; wings pale yellowish with the base somewhat reddish.

Length 4 mm.

California. (Translation).

Nemopoda coerulifrons Macquart

Macquart, Dipt. Exot., Suppl., II. 2, 94 (110) (1847)

Aldrich, Catalog N. Am. Dipt. 620 (1905) *caeruleiformis*, lapsus

Male. Thorax black, abdomen æneous, front blue-black, a little yellowish anteriorly, the face yellowish; sides of the thorax shining, with greenish tinge, the notum dull; legs yellowish, the hind femora a little brownish. Length 3 mm.

Philadelphia. (Translation).

Nemopoda cubensis Bigot

Bigot, Annales Soc. Ent. Fr., 1886, 390 (1886)

Male. Shining black; face and cheeks testaceous; antennæ yellowish, the third joint brownish above; halteres yellowish; legs yellow, except the femora and posterior tibiæ, which are exteriorly brownish; the last two joints of all the tarsi black; wings hyaline, the very base in front marked with black.

Length 3 mm.

Cuba. (Translation).

Nemopoda obscuripennis Bigot

Bigot, Annales Soc. Ent. Fr., 1886, 392 (1886)

Male. Entirely black, subshining with grayish lustre; front, face and cheeks pruinose; vertex blackish, marked with a yellowish spot above the antennæ; pleuræ and coxæ, as well as the legs, pruinose; calypteres white, halteres pale yellow; tibiæ reddish, the base of the femora and the knees narrowly tinged with yellow; wings gray, the front border and the crossveins brown; femora and tibiæ armed exteriorly with long scattered bristles.

Length 4.5 mm.

California. (Translation.)

Genus **ENICITA** Westwood

Westwood, Introd. Classif. Ins., I. 148 (1839)

Enicopus Walker (not Stephens, 1830), Ent. Mag., I. 253 (1833)

The European type species of this genus is a small black fly with the following characteristics: Bristles of the head rather weak, one pair of verticals, postverticals weak, orbital bristles reduced, oral bristles hair-like. Mesonotal setulæ small, one pair of dorsocentrals, two pairs of scutellars, two notopleurals, one postalar. Abdomen slender, rather long and constricted at the base, hypopygium large, the valves with long terminal portion. Wings without stigma, all three basal cells developed. Front and middle legs of the male abnormal, the front femora with a strong basal flexor spine, middle tarsi long, the joints expanded.

The type species, *E. annulipes* Meigen, is closely related to Themira, the females showing but poor diagnostic differences although the males have somewhat different pedal modifications. Mr. Brunetti has sent us Indian specimens determined as *Enicita annulipes* which differ greatly from the European species, being large and

stocky with robust abdomen and having strong bristles on the head. The occurrence of the genus in America has been considered doubtful, being based on Bigot's *Enicopus fuscus*, the description of which follows. A second species is herewith described which likewise is based on a female. The discovery of the males of these species may show them not to be congeneric with the European genotype, but in the meantime they find their best assignment here.

Enicita fusca Bigot

Bigot, Annales Soc. Ent. Fr., 1886, 387 (1886) *Enicopus*

Entirely dark brown except the yellow antennæ, the white knob of the halteres and the yellow legs whose tibiæ excepting the front pair are brownish and whose tarsi apically are brown; wings nearly hyaline.

Possessing only a single female of this species I can not assign it with absolute certainty to the genus Enicopus.

Length 4.5 mm.

Mexico. (Translation).

Enicita bispinosa, sp. nov.

Head and thorax subshining piceous black, abdomen polished æneous black, front, face, cheeks, antennæ, mouthparts, humeri, pectus, propleuræ and the suture between the mesopleura and pteropleura reddish. Antennæ very short, the third joint brownish, arista blackish; ocellar and the single vertical bristle strong, postverticals weak, orbitals not developed. Thoracic bristles limited to one dorsocentral, one notopleural and one pair of approximate scutellars; mesopleuræ shining, sternopleuræ white-pruinose, the coating continuous but more attenuated on the pteropleuræ and metanotum. Abdomen narrow, strongly constricted at the end of the relatively long first segment, sparsely setulose. Legs long and slender, entirely yellow, front femora with two stout black spines placed close together on the under side three-fifths the distance to the knee, middle tibiæ with a few apical bristles, legs otherwise bristleless, posterior metatarsi nearly equalling the remaining joints together. Halteres with white knob and blackish root; calypteres and fringe dusky. Wings hyaline, sections of the fourth vein proportioned 4 : 3 : 8, of the fifth vein 3 : 1, anal vein abruptly ending two-thirds the way to the margin.

Length 4 mm.

A single female, Austin, Texas. The species differs from

Themira in having pollinose pteropleuræ. The reduced fronto-orbital and postvertical bristles and the constricted narrow abdomen place it in Enicita. The femoral spines are much more pronounced than in *Themira flavicoxa*.

Genus **THEMIRA** Desvoidy

Desvoidy, Myodaires, 746 (1830)
Schiner, Faun. Austr. Dipt., II. 181 (1864)
Rondani, Bull. Soc. Ent. Ital., VI. 177 (1874)
Frey, Deutsch. Ent. Zts., 1908, 585 (1908)

Cheligaster Macquart, Hist. Nat. Ins. Dipt., II. 479 (1835)
Halidaya Rondani, Dipt. Ital. Prodr., I. 117 (1856); VIII. Tanypez., 177 (1874)

Black species, ranging from two to five millimeters in length, head globular, occiput rounded and smooth, face carinate, front broader than long and extending over the base of the antennæ; antennæ small, the third joint rounded, the arista tapering to a fine hair; oral bristles small and hair-like, the vibrissæ but little developed; one pair each of vertical and fronto-orbital bristles, the postverticals strong, ocellar bristles long. Mesonotum black, not polished but more or less subshining through a weak pollinose coating; sternopleuræ entirely pruinose; acrostichal and dorsocentral setulæ forming three distinct rows, the hindmost pair of dorsocentral bristles alone developed, two scutellar bristles, one or no humeral bristle, one or two notopleurals. Front femora of the male greatly deformed, bearing tubercles and spines, hind legs of the male sometimes also deformed. Abdomen not broad and of uniform width, polished, devoid of bristles, the setulæ sparse; male genitalia prominent, sometimes furnished with curious bunches of long hairs. Wing-spot absent, the veins firm, anterior crossvein near the middle of the discal cell, anal vein abbreviated about half way to the margin.

Genotype: *Th. pilosa* Desvoidy, by Coquillett's designation (Proc. U. S. Nat. Mus., XXXVII. 614, 1910).

Sex dimorphism finds a striking elaboration in this group. The males sometimes have remarkable hirsute structures and forceps in connection with the genitalia and also

exhibit to a specialized degree the tertiary sex modifications of the front femora and front and hind tibiæ. The various development of such male characters has led to the subdivision of the group into genera, which being based on the one sex alone have doubtful validity and are here regarded as subgenera. Enicita should probably also have a similar disposal.

KEY TO THE NORTH AMERICAN SPECIES OF THEMIRA

1. Abdomen of the male bearing a conspicuous bundle of long curling hairs arising from a distinct, articulated process at each side of the greatly enlarged fourth ventral segment; humeral bristle present; an outstanding bristle present at the base of the front femora of the male underneath.
(Subgenus CHELIGASTER Macquart) 2.

Abdomen narrowed apically, without such bundles of hairs, at most with a few long hairs from each side of the smaller fourth sternite, usually concealed beneath the hypopygium; no basal bristle on front femora.
(Subgenus THEMIRA Desvoidy) 5.

2. Sternopleuræ largely shining; upper side of front femora ♂ fringed with numerous projecting bristles, the under side with a wide and deep emargination, front metatarsi ♂ continued beyond the insertion of the next joint as a long spinose process; abdomen ♂ depressed, pyriform, the fourth sternite projecting laterally as wide as the abdomen is long, its filaments abundant and arising in two bundles from each side.
malformans, n. sp.

Sternopleurae entirely opaque; front femora not ciliate beyond base; abdomen ♂ oval, not widest posteriorly, ♂ filaments arising as a single bunch. 3.

3. Larger species, measuring 4 mm.; wings with the hind crossvein about equal to the last section of the fifth vein; front coxae bearing setulae, front femora stout basally, bristly above toward apex, in ♀ with a row of short bristles at middle of under side, front tibiae finely pollinose, middle tibiae of both sexes with a preapical flexor bristle, hind tibiae stout, not indented, hind metatarsi short and thick; anal brush shorter.
putris Linnaeus

Smaller species, measuring 3 mm.; wings with hind crossvein shorter than the last section of the fifth vein; front coxae glabrous and polished, front femora not ciliate above, ♂ with long basal flexor bristle, ♀ with or without flexor bristles, front tibiae shining, hind tibiae ♂ indented at middle, hind

metatarsi slender; anal brush long; penultimate segment of ♂ abdomen with prominent marginal bristles.

(incisurata, n. sp.) 4.

4. Tarsi slender, the joints longer than wide; front femora ♀ with four or five flexor spinous bristles at the middle.

var. **incisurata,** sens. str.

Last three tarsal joints ♂ not longer than wide, those of middle tarsi cordiform; front femora ♀ with one or no flexor bristle.

var. **latitarsata,** n. var.

5. Mesonotum uniformly lightly pollinose, humeral bristle present; coxae, especially the front pair, yellow or brown, front femora ♂ notched and bearing a central yellow thorn flanked by three bristles, distal to which is a black peg-like bristle, the middle of the front tibiae ♂ correspondingly notched, hind legs normal; veins brown. **flavicoxa,** n. sp.

Sides of mesonotum polished, only the central stripe pollinose, humeral bristle absent; coxae black and largely pollinose, middle thorn of front femora ♂ black; veins blackish.

minor Haliday

Themira putris Linnaeus

Linnaeus, Faun. Suec., 2 edit., 456, var. *fimeti* (1761) *Musca*

Scopoli, Entom. Carn., 904 (1763) *Musca*

Fabricius, Spec. Ins., II. 445 (1781) *Musca;* Syst. Antl., 323 (1805) *Tephritis*

Gmelin, Syst. Nat., V. 2849 (1793) *Musca*

Schrank, Fauna Boica, III. 2471 (1803) *Musca*

Fallen, Dipt. Suec. Ortalid., 21, (1820) *Sepsis*

Meigen, Syst. Beschr. zwfl. Ins., V. 292 (1826) *Sepsis*

Haliday, Entom. Mag., I. 170 (1833) *Sepsis*

Macquart, Hist. Nat. Dipt., II. 479 (1835) *Cheligaster*

Staeger, Kröjer's Tidskr., I. 29 (1844)

Zetterstedt, Dipt. Scand., VI. 2290 (1847) *Sepsis*

Walker, Ins. Brit., II. 212 (1853)

Schiner, Faun. Austr. Dipt., II. 182 (1864)

Rondani, Bull. Soc. Ent. Ital., VI. 178 (1874)

fimeti Schrank, Faun. Boica, III. 2471 (1803)

Entirely black except the yellow halteres and calypteres, sternopleuræ gray pruinose, scutellum velvety. Male legs black throughout, front coxæ armed with weak bristles at the tip and whitish pruinose on the inner side; front femora considerably enlarged, increasing in size abruptly at the base for about one-third the length, the under side bearing a blunt, thumb-like projection and a smaller thorn at the thick-

est portion and a slender finger-like projection at one-third the distance from the tip, front tibiæ very narrow for one-third the distance from the base then considerably enlarged, bearing a flap-like projection corresponding to that of the femur, first joint of the tarsi short, thickened, bearing a dense sole of uniform yellowish setulæ on its under side, the second joint as long as the first, all the joints with dense setulæ; middle legs simple; hind tibiæ compressed, densly hairy, bearing a long flattened velvet-black area on the exterior face, hind metatarsi tapering, somewhat longer than the following two joints. Abdomen polished, not bristly but with loose long hairs at the end, male genitalia with a bunch of very long curling hairs on each side. Wings lightly tinged with brownish, three and a half times as long as wide, costa nearly straight, its last three sections proportioned 2.6 : 1 : 0.5, veins brownish, the costa and first vein nearly black, first vein ending opposite the anterior crossvein near the middle of the discal cell, posterior crossvein equal to or longer than the last section of the fifth vein.

Female front femora with a row of five or six rather stout spines, but not deformed.

Length 5 mm.

This species, originally described from Europe, frequents putrifying organic matter such as sewage. It is locally very common as we have sixty-five specimens before us. Dr. Aldrich has taken it attending plant lice on cottonwood trees. The following localities are represented: **Maine**, Fort Kent (Johnson); **New Hampshire**, Glen House (Johnson); **Massachusetts**, New Bedford (Hough); **Ontario**, London (Hough); **Illinois**, Algonquin (Nason); **South Dakota**, Brookings (Aldrich); **British Columbia**, Nelson (Melander); **Idaho**, Moscow (Aldrich); **Washington**, Pullman, Seattle (Melander); **California**, Pacific Grove (Aldrich).

Themira incisurata, sp. nov.

Shining black species, sternopleuræ white pruinose. Front femora of the male not swollen but twisted, at the middle of the under side bearing a translucent expansion capped with three thorn-like projections, the distal one hooked backward, the middle one spine-like, the proximal thorn curved forward and yellowish in color; front tibiæ slightly curved on the outer side and increasing in size toward the tip, the under side bearing a pronounced oblique

saucer-shaped, spineless tubercle beyond the middle, proximal to which is a slender hook, split at the tip, front metatarsi slightly narrowed beyond the middle, as long as the following two joints together, the second joint shorter than the third; hind femora elongated, rather densely hairy; hind tibiæ elongated, with a decided incision at the middle of the under side; hind metatarsus nearly as long as the remaining joints together, all the tarsal joints slender and longer than wide; legs of the female simple, the front femora with about five small spines placed close together at the middle of the under side. Abdomen black, the last two segments with long fine bristles; hypopygium on each side with a thick bunch of extremely long hairs arising from a lengthened process from the under sides of the fourth segment, terminal prongs of the hypopygial lamellæ parallel. Wings three times as long as broad, the costa rounding, veins brown to black, first vein ending opposite the anterior crossvein, posterior crossvein from one-half to one-third as long as the last section of the fifth vein, last three sections of the costa proportioned 1.2 : 1 : 0.4.

Length 3 mm.

Type from Mt. Constitution, Orcas Island, Washington. Six paratypes from Olga and Friday Harbor, Washington (Aldrich, Melander).

Temira incisurata, var. **latitarsata**, var. nov.

The preceding form is described from specimens taken on the islands in Washington Sound. A series of other specimens is structurally the same except for a widening of tarsal joints in the male, especially those of the middle legs. The females differ in a reduction of the spines of the front femora, the western specimens having but one outstanding spine at the middle of the under side and the eastern specimens showing none at all. First joint of middle tarsi nearly as long as the remainder of the tarsus, second joint widening toward the apex, third, fourth and fifth joints, each cordate, wider than long. The last three joints of the other tarsi not longer than wide.

Twenty-one specimens. **Washington**, Pullman (Melander), Keyport (Aldrich); **Oregon**, Corvallis (Cordley); **Montana**, Libby, Flathead Lake (Melander); **Vermont**, Lyndell (Melander), Summit of Jay Peak (Morse); **Pennsylvania**, Delaware Co. (Cresson).

Themira malformans, sp. nov.

Male. Piceous black, the halteres and calypteres yellow; occiput subshining, mesonotum and most of sternopleuræ polished. Postvertical bristles longer than the ocellars, face and cheeks black, oral hairs relatively long, the vibrissæ not differentiated. Legs black but the middle tarsi yellowish, front coxæ nearly glabrous and polished, front femora stout and extraordinarily deformed, ciliate above with about ten long bristles, with a moderately long basal flexor bristle, deeply excavated beyond the prominent bifid middle tubercle and with a thin finger-like process arising from the base of the excavation; front tibiæ correspondingly and strikingly deformed, swollen to the middle and then abruptly excised, with an anterior round tubercle and an extensor stout and long spine in the middle; front metatarsi as long as the following two joints together, the articulation with the second joint situated on the flexor side one-fourth the distance from the tip, the terminal part tipped with two bristles; anterior side of the middle femora pectinate with short bristles; hind tibiæ pilose, terminated by a long curved spur; hind metatarsi depressed and with a sole of yellow pubescence. Wings lightly infumated, veins blackish, costal sections proportioned 1.5 : 1 : 0.4; anterior crossvein at the middle of the discal cell, posterior crossvein as long as the last section of the fifth vein. Abdomen flat and broadened posteriorly, the fourth ventral segment extraordinarily enlarged so as to project on each side where it is furnished with a double bundle of long curving filaments which reach around behind the abdomen and interlock; hypopygium hairy, its base setose.

Female of normal structure, legs not deformed or bristly, the under side of the front femora with two approximate spines; veins brown, anterior crossvein before the middle of the discal cell.

Length 2 to 3 mm.

Hudson Bay. Collector unknown.

Themira flavicoxa, sp. nov.

Vertex shining black, the occiput lightly pollinose; antennæ small, dusky brown, arista black; face and cheeks yellowish, the clypeus black, oral hairs uniform, the single vibrissa well developed. Thorax black except the pruinose sternopleuræ, the notum entirely and uniformly coated with sparse pollen, acrostichals microscopic. All the coxæ yellow, the remainder of the legs black; front femora of the male

slightly enlarged to about three-eighths the distance from the base and then gradually decreasing in size toward the tip, at the middle bearing a small yellow finger-like projection flanked outwardly by three black bristles and inwardly and distally by a stout blunt, peg-like thorn, no basal bristle present; front tibiæ of the male narrow at the base and enlarged toward the middle, the under side bearing two flap-like projections corresponding with the femoral armature; tarsi densely pubescent underneath, the front metatarsi as long as the following two joints togther; middle and hind legs simple. Sides of the abdomen parallel, fourth sternite swollen broadly V-shaped and bearing a small bundle of long hairs on each side, end-process of the hypopygial valves small with parallel sides and pointed tip. Wings hyaline, over three times as long as wide, costa and first vein blackish, other veins brown, anterior crossvein at the middle of the discal cell, posterior crossvein a little shorter than the last section of the fifth vein, sections of the costa proportioned 2 : 1 : 0.4.

Female legs simple, the front femora with a pair of short stout bristles at the middle of the flexor side.

Length about 3 mm.

Type from Cold Spring Harbor, Long Island, New York (Melander). Thirteen paratypes from the same place and from Yalesville, Connecticut (Viereck), Allegheny and Delaware Co., Pennsylvania (Cresson) and Chicago, Illinois (Melander). The female of this species strikingly resembles the female of *Enicita annulipes* Meigen.

Themira minor Haliday

Haliday, Ent. Mag., I. 170 and 255 (1833)
Schiner, Faun. Austr. Dipt., II. 183 (1864)
lucida Stæger, Kröjer's Tidskr., I. 32 (1844) *Sepsis*
Zetterstedt, Dipt. Scand., VI. 2299 (1847) *Sepsis*
Schiner, Faun. Austr. Dipt., II. 183 (1864)
Rondani, Bull. Soc. Ent. Ital., VI. 177 (1874) *Meroplius*

Entirely black except the white halteres and calypteres; sternopleuræ and inner sides of the coxæ white-pruinose; occiput and central stripe of the mesothorax between the dorsocentral setulæ lightly pollinose, the humeri and a space above the notopleural suture highly polished. Oral hairs short, the front pair slightly stouter. Legs, including the coxæ, entirely black, in the male the front femora of

normal thickness but furnished with a flexor thorn-like bristle at the middle, anterior to which is a blunt, blackish, finger-like tubercle, while distal to the tubercle is a short, thick, curving bristle; the front tibiæ correspondingly modified by a strong excision on the flexor side at the base of which arises a flat finger-like tubercle and a stout tapering bristle; posterior legs normal, not long-pilose; legs of the female simple. Wings lightly infumated, over three times as long as broad, veins black or blackish, sections of the costa proportioned 1.6 : 1 : 0.3. Abdomen narrowly cylindrical and apically tapering, not fringed with long hairs, hypopygium without bunches of hair, simple, terminal, the valves ending in apposed broad, blunt, hatchet-like processes.

Length 2 to 3.5 mm.

This European species has not been previously recorded from America. Specimens from Austria, received from Prof. G. Strobl, have been compared with about fifty from Greenfield and Petersham, Massachusetts (Melander); Scituate, Massachusetts (Johnson); Lynden, Vermont (Melander), and Long Island, New York (Melander).

Genus **AMPHIPOGON** Wahlberg

Wahlberg, Oefvers. af. Kongl. Vetensk. Akad. Foerh., X. 217 (1844)

Zetterstedt, Dipt. Scand., VII. 2684 (1848)

Mik, Verh. z. b. Ges. Wien., XXVIII, 473-476 (1878)

Macrochira Zetterstedt, Ins. Lapp. Dipt., 784 p. p. (1838)

Head globose, the lower part of the face bearded in the male, in the female with rigid vibrissæ, the vertex with about ten strong bristles, arista bare. Mesonotum very finely pubescent, the lateral and posterior bristles rigid but few in number, scutellum quadrisetose. Hind femora of the male with long and dense pile toward the base. Wings unspotted.

A single European boreal and alpine species, *A. spectrum* Wahlberg, is known.

Genus **PANDORA** Haliday

Haliday, Ent. Mag., I. 170 (1833)

Anisophysa Macquart, Hist. Nat. Dipt., II. 545 (1835)

? **Saltella** Desvoidy, Myodaires, 746 (1830)

Schiner, Faun. Austr. Dipt., II. 183 (1864)

Small, opaque-dusted, rather flattened flies, black with

parts reddish. Face with a strong median swelling, the antennal groves deep, vibrissal angles protruding but rounded; palpi vestigial but ending in a seta; antennæ shorter than the face, the last joint orbicular, arista slender and bare; oral bristles rather pronounced, the anterior pair developed into short stiff vibrissæ; bristles of the head usually strong, one fronto-orbital, two verticals, post verticals and ocellars long. Notum with three rows of strong acrostichal setulæ, two pairs of dorsocentrals at the posterior end of rows of setulæ, four scutellars, one humeral, two notopleurals, one supra-alar, one postalar, one mesopleural. Wings without a subapical spot, first and second basal cells fused, anal vein very short, first posterior cell narrowed. Abdomen short and depressed, basal segments devoid of macrochætæ, hypopygium small. Front femora of the male armed with spines beneath.

This Europen insect has apparently been introduced into the United States only recently as it was not known to the older collectors. It has become widely spread and is now not rarely met with.

Hendel, adopting Schiner's suggestion, replaces the customary name Saltella by Pandora on the ground that Desvoidy dealt with some other insect than the present genus. Desvoidy's Saltella is unknown but his name has been applied to the following species because one of the species, *nigripes* Desvoidy, originally included in Saltella is a synonym of *scutellaris* Fallen.

Pandora scutellaris Fallen

Fallen, Dipt. Suec. Heteromyz., 10 (1820) *Piophila*
Meigen, Syst. Beschr. zwfl. Ins., V. 397 (1826) *Piophila*
Haliday, Entom. Mag., I. 169 (1833)
Macquart, Hist. Nat. Dipt., II. 544 (1835) *Anisophysa*
Loew, Settin. Ent. Ztg., 1841, 182 (1841) *Saltella*
Zetterstedt, Dipt. Scand., VI. 2520 (1847) *Saltella*
Walker, Ins. Brit. Dipt., II. 213 (1853) *Saltella*
Schiner, Faun. Austr. Dipt., II. 184 (1864) *Saltella*
Rondani, Bull. Soc. Ent. Ital., VI. 179 (1874) *Saltella*
Johnson, Psyche, XVII. 234 (1910) *Saltella*, occ. in America
distincta Meigen, Syst. Beschr. zwfl. Ins. VII. 360 (1838) *Piophila*

Becker, Zts. Hym. Dipt., II. 249 (1902) *Saltella*

ferruginea Desvoidy, Myodaires, 744 (1830) *Nemopoda*

Macquart, Hist. Nat. Dipt., II. 482 (1835) *Nemopoda*

Meigen, Syst. Beschr. zwfl. Ins. VII. 352 (1838) *Nemopoda*

humeralis v. Roser, Correspbl. landwirtsch. Ver. Württemb., 61 (1840) *Piophila*

Becker, Jahresber. Ver. vaterl. Naturk. Württemb., XV. 56 (1902) *Saltella*

melanocephala var. Drapiez, Ann. gener. Sci. phys. (1820) *Ochthera*

Bergroth, Entom. Nachr., XIII. 151 (1887) *Saltella*

nigerrima Rondani, Bull. Soc. Ent. Ital., VI. 180 (1874) *Saltella*

nigripes Desvoidy, Myodaires, 747 (1830) *Saltella*

Macquart, Hist. Nat. Dipt., II. 665 (1835) *Saltella*

Meigen, Syst. Beschr. zwfl. Ins., VII. 352 (1838) *Saltella*

Walker, Entom. Mag., I. 255 (1833) *Sepsis;* Ins. Brit. Dipt. II. 213 (1853) *Saltella*

parmensis Rondani, Bull. Soc. Ent. Ital., VI. 179 (1874) *Saltella*

pectoralis Zetterstedt, Dipt. Scand., VI. 2515 (1847) *Saltella*

ruficoxa Macquart, Hist. Nat. Dipt., II. 481 (1835) *Nemopoda*

Meigen, Syst. Beschr. zwfl. Ins., VII. 351 (1838) *Nemopoda*

scutellata Macquart, Hist. Nat. Dipt., II. 481 (1835) *Nemopoda*

Meigen, Syst. Beschr. zwfl. Ins., VII. 351 (1838) *Nemopoda*

sellata Curtis, Guide to Arrangem. Brit. Ins., 1297 (1829) *Saltella*

Haliday, Entom. Mag., II. 186 (1834)

sphondylii Shrank, nom. nud.

Loew. Jahrb. gel. Ges. Krak., XLI. 15 (1870) *Saltella*

Body and legs variable in color as indicated in the adjoining table.

Front coxæ robust, front femora of the male gradually enlarged to the middle and then decreasing toward the tip, the under side bearing six to eight short stout spines, four on the middle inner and four on the middle outer sides; front tibiæ short robust, the under side beset with a row of small spines; front tarsal joints densely pubescent; middle coxæ with an apical bristle; middle femora covered with fine black hairs, the inner sides bearing seven small spines from the middle to the tip; middle tibiæ enlarged apically, bearing from six to eight setæ on the outer side and two on the inner; middle tarsi pubescent, the under side bearing rows of long setulæ in a comb-like arrangement; outer apical edges of hind femora armed with three stout spines; hind tibiæ without spines. Wings with a slight yellowish tinge, costa black, veins yellow, anterior crossvein at the middle of the discal cell, posterior crossvein about twice as long as the

last section of the fifth vein, anal vein not reaching the margin of the wing.

Length 3 to 4 mm.

The species is extremely variable as is indicated from the host of synonyms, and furthermore differs in the sexes. Macquart was impressed with the sex differences sufficiently to name the genus *Anisophysa*, referring to the narrow abdomen of the male and the broad abdomen of the female. We have twenty-five specimens from the United States and have compared them with European specimens received from Professor Strobl. The following localities are represented among the material: **Vermont**, Lynden (Melander); **Massachusetts**, Greenfield (Melander); **New York**, Hamburg (Van Duzee), Cold Spring Harbor, Geneva (Melander); **Ontario** Waubamic (Parish); **Illinois**, Urbana, (University of Illinois). The following variations occur in the specimens before us. The two forms described by Rondani are listed as distinct species in the catalog of Palæarctic Diptera but although each variation is reasonably constant all the forms appear to comprise but a single species. They occur together in the same sweepings. It would be interesting to know whether these have arisen anew as mutants in the descendants of a single introduced family or whether the several variations have all been imported into the United States.

1\. Legs entirely black; mesonotum subshining; length 3 mm.
var. **nigerrima** Rondani
At least the coxae and trochanters yellowish; mesonotum opaque; slightly larger forms. 2.

2\. Legs largely black; body almost wholly black. 3.
All the femora, the middle tibiae of ♂ and the pleurae, sides of mesonotum, base and apex of abdomen reddish.
var. **parmensis** Rondani

3\. Body except the hypopygium black, the numeri rarely reddish, scutellum opaque black. var. **ruficoxa** Macquart
Humeri and more or less of scutellum reddish.
var. **scutellaris** Fallen, s. str.

Genus **CENTRIONCUS** Speiser

Speiser, Kilimandjaro-Meru Exp., 10, 5, 190 (1910)

Described as suggesting a Diopsid with the head of a

Sepsid. An abstract of Speiser's lengthy diagnosis is here given.

Head round, the occiput strongly developed, clypeus prominent, front about one-third the width of the head, a single strong fronto-orbital, one vertical bristle; palpi subulate; antenna short, the third joint circular, the arista plainly pubescent. Pleuræ with tomentose spot, scutellum with two thorns each bearing a bristle, three notopleurals, one slender presutural, one short supra-alar and one strong postalar. Nearly one-half of the abdomen taken by the first segment, the others decreasing in length; male genitalia swollen, female abdomen tapering, the last segment forming a sort of ovipositor. Wings as in Sepsis, without any apical spot, the anal vein somewhat lengthened.

The single species, *C. prodiopsis*, comes from Kilimandjaro, Southeastern Africa.

Genus **MEGAMERINA** Rondani

Rondani, Dipt. Ital. Prodr., IV. 10 (1861); Tanypez., Bull. Soc. Ent. Ital., VI. 172 (1874)

Lissa Meigen, Syst. Beschr. Zwfl. Ins., V. 370 (1826, not Leach, Crustacea, (1815)

Schiner, Faun. Austr. Dipt., II. 189 (1864)

Meganeurina lapsus, Becker, Katal. Palæarct. Dipt., IV. 154 (1905)

The typical European species, *M. dolium* Fabricius (*loxocerina* (Fallen) with its elongate abdomen and lengthened legs resembles a Calobatine fly. The entire absence of oral bristles has placed the insect in the Psilidæ where it is aberrent in having a distinct auxiliary vein. The occurrence of the genus in North America is based on two species described by Walker and Bigot and certainly needs verification before final acceptance. Schiner's characterization of Lissa furnishes the following abstract:

Head globose, face inflexed, medially carinate, eyes large, nearly reniform owing to their prominent posterior margin, cheeks narrow, front broad and bare, arista pubescent. Thorax bare, punctured, scutellum small and with two bristles; abdomen long and narrow, male genitalia projecting underneath the abdomen. Femora with short spines beneath, the

hind pair thickened and much lengthened. Third and fourth veins parallel, second basal and anal cells long, anal vein complete.

Four American species have been described as belonging to this genus. One of them *Lissa carbonaria* Walker, List, IV. 1047 (1849), has been assigned to Cordylura by Coquillett. A Virginia specimen received from Nathan Banks agrees with Walker's description and is surely a Cordylura. Two other species described by Walker, *Lissa varipes,* p 1046, and *L. cornuta,* p. 1047, also belong to the Cordyluridæ and have been assigned to the genera Parallelomma and Hexamitocera, respectively. The other species, *Megamerina fulvida* Bigot, can not be definitely located in this genus from the meager information afforded by the following description:

Megamerina fulvida Bigot

Bigot, Annales Soc. Ent. Fr., 1886, 384 (1886)

Male. Fulvous. The third joint of the antennæ a little brownish above; scutellum black on each side; halteres yellowish white; abdomen with the incisures and the apex more or less broadly brownish; front femora slightly brownish above and toward the tip, all the tibiæ and all the tarsi more or less brownish; wings very pale yellow, tip, costa and cross-veins narrowly bordered with brown.

Female. Scutellum entirely black.

Length 6 mm., excluding the ovipositor.

Mexico. The preceding is a translation of the French part of the description.

Family PIOPHILIDAE

The flies included in this family rarely exceed five millimeters in length, and are usually glistening black or slightly bluish metallic in lustre. Face not carinate, occiput more or less flattened; always two pairs of vertical bristles; postvertical bristles divergent; fronto-orbital bristles varying from two pairs to none; antennæ decumbent, the third joint elongate oval, arista bare in the American species; bucca rarely fringed with hairs, the oral vibrissæ usually prominent, genæ not differentiated as a linear orbital boundary; palpi

well developed. Mesonotum almost always finely pubescent and polished; sternopleuræ never pruinose; one pair of dorsocentral bristles, four scutellar bristles. Legs of the male never toothed or deformed, the front femora usually furnished with long but delicate bristles. Abdomen more or less polished, pubescent but without bristles, broad, depressed, not constricted at the base; genitalia of the male more or less hidden, asymmetrical; ovipositor extensile. Auxiliary vein terminating close to the end of the first vein, the costa broken at or near the termination, third and fourth veins parallel or more or less diverging, anal vein usually curved and evanescent apically, discal cell usually large, with the posterior crossvein usually long.

KEY TO THE GENERA OF THE PIOPHILIDAE

1. Third vein nearly or quite parallel with the fourth and gently curving backward. 2.
   Third vein curving forward, diverging from the fourth, anal vein curved, wings widely rounded apically. (Europe).
   PSEUDOCEPS Becker
2. Anterior crossvein at or beyond middle of discal cell. 3.
   Anterior crossvein distinctly before middle of discal cell; proboscis somewhat projecting and bulbous; front rather narrow. (Europe). RHYNCHAEA Zetterstedt
3. Arista bare; abdomen with five segments. 4.
   Arista tomentose; palpi hairy at apex and beneath; abdomen with six segments. (Europe). SCOTIMYZA Macquart
4. Body and legs slender and bare, femora somewhat curved; head spherical, face vertical, third antennal joint elliptical; first posterior cell narrowed apically, anterior crossvein at outer fourth of discal cell; the shining ocellar triangle attaining edge of front. (Egypt). TOXOPODA Macquart
   More robust, more or less hairy; occiput flattened, ocellar triangle shortened; anterior crossvein between middle and last third of discal cell. 5.
5. First and second antennal joints minute, the second with distinct dorsal bristle, the third round, relatively short; front in profile slightly convex and rounding toward antennæ; head globose, usually one or more orbitals, inter-frontal short hairs usually present although sparse; bristle at base of costa distinct. 6.
   Second antennal joint variable in length but obviously longer than first, its upper surface setulose, the bristles scarcely

evident, third joint rounded, quadrate, longer than deep; head more or less conical, face strongly retreating, fronto-orbital bristles absent, front flattened, slightly concave toward antennae, more or less projecting, especially in male, interfrontal hairs typically absent; basal bristle of costa weak; one pair of dorsocentrals. (North America).

PROCHYLIZA Walker

6. Two pairs of dorsocentral bristles present, two sternopleurals, one humeral, two fronto-orbitals, ocellar bristles reaching to lunule; front trapezoidal, narrowing anteriorly, shining; calypteres vestigial and dusky; first vein ending before middle third of wing; reddish species with a pronounced subapical wing-spot. (Europe; North America).

MYCETAULUS Loew

One pair of dorsocentral bristles, no sternopleurals, humerals usually absent, none to two fronto-orbitals, ocellar bristles usually short; front quadrate, not polished; calypteres white and densely fringed; black species, the wings without a definite subapical dark spot. (Cosmopolitan).

PIOPHILA Fallen

Genus **TOXOPODA** Macquart

Macquart, Dipt. Exot., Suppl. IV., 272 (299) (1851)

Body slender, bare. Head spherical. Proboscis and palpi retracted in the mouth cavity. Face bare, vertical; epistome prominent. Front rather broad anteriorly, widening behind, ♂, bare; ocelli present; antennæ incumbent, not reaching to the epistome, first two joints short, the third oblong, elliptical, arista bare. Eyes round. Thorax somewhat elongate. Abdomen oblong, flattened, with five segments. Legs rather long, bare; the femora somewhat curved. Calypteres undeveloped. Wings with the first vein simple, third and fourth veins converging apically, crossveins approximated. Translation.

But a single species is known, *T. nitida* Macquart, from Egypt.

Genus **PROCHYLIZA** Walker

Walker, List Dipt. Brit. Mus., IV. 1045 (1849)

Head cone-shaped; front concave toward the antennæ, flattened, not rounding but more or less projecting, especially in the male; two vertical bristles, no fronto-orbitals, inter-

frontal hairs usually absent; face strongly retreating, nearly horizontal, cheeks narrow; antennæ long, the second joint obviously longer than the first, its upper surface setulose, the dorsal bristle scarcely evident, the third joint rounded, quadrate, longer than deep, the arista bare. Mesonotum with abundant scattered very fine hairs, the mesopleuræ and sternopleuræ hairy; one pair of dorsocentral bristles, four scutellars, one postalar, one supra-alar, one intra-alar. Abdomen depressed, broad, elliptical in the female, narrower in the male; genitalia of the male small but not hidden; ovipositor (sixth segment) of the female tubular and extended; abdomen without macrochætæ but with fine hairs. Legs simple, the front femora with outstanding flexor bristles. Costa with the basal bristle weak.

But a single species is known, which is widely distributed over North America.

· **Prochyliza xanthostoma** Walker

Walker, List Dipt. Brit. Mus., IV. 1045 (1849)
Osten Sacken, Cat. Dipt. N. Am., 199 (1878)

Front and occiput black, lower face and cheeks pale yellow; antennæ entirely black. Body black, polished, propleuræ white pruinose, metapleuræ black villous; hairs of the notum and abdomen short and black; scutellum narrowly triangular, convex and smooth above. Anterior coxæ yellow, the trochanters, base of the front femora and of the front tibiæ, middle legs and hind tibiæ and tarsi yellow, the remainder of the legs blackened. Calypteres white and with a dense fringe; halteres yellow. Wings hyaline, veins yellowish, anterior crossvein near three-fifths the length of the discal cell, last section of the fifth vein about half the length of the posterior crossvein, anal vein evanescent before the margin.

Length 3 to 5 mm.

The species is remarkably variable in the shape of the head. Some males possess a regular cone-like head with greatly elongated antennæ; as the other extreme some females show a globular head with very short antennæ. The latter variation closely approaches *Piophila affinis* in color but is readily distinguishable by the setulose upper surface of the second antennal joint.

The species is common. We have over a hundred mounted specimens collected from garbage and from the windows of houses from the following localities: **Massachusetts**, New Bedford (Hough); **Pennsylvania**, Delaware County (Cresson), Pittsburg (Ehrman); **Georgia**, Tifton (Hough Coll.); **Alabama** (Baker); **Louisiana**, Opelousas (Hough Coll.); **Texas**, Austin (Melander); **Illinois**, Chicago (Melander), Homer, St. Joseph (Coll. Univ. Ill.); **South Dakota**, Brookings (Aldrich); **Colorado** (Baker); **Montana**, Glacier Park, Flathead Lake (Melander); **Idaho**, Troy (Mann); **Washington**, Tacoma, Roche Harbor, Quilcene (Melander), Friday Harbor (Aldrich); **California**, Berkeley Hills (Cresson); **Alaska**, Douglas (Jenne). The species has been recorded also from New Hampshire, New Jersey, and Kansas, as well as from the original locality at St. Martin's Falls, Canada.

Genus **PIOPHILA** Fallen

Fallen, Spec. Ent. Meth. Exhib., 20 (1810); Dipt. Suec., Heteromyz. 8 (1820)

Meigen, Syst. Beschr. Zwfl. Ins., V. 394 (1826)

Zetterstedt, Dipt. Scand., VI. 2507 (1846)

Schiner, Faun. Austr. Dipt., II. 184 (1864)

Rondani, Bull. Soc. Ent. Ital., VI. 248 (1874)

Stearibia Lioy, Atti Inst. Veneto (3) IX. 1105 (1864)

Tyrophaga Kirby, Introd. Ent., II. 283 (1817)

Head rounded, the occiput flattened, the face nearly vertical or somewhat receding, the cheeks enlarged posteriorly; antennæ short, the second joint short, with an outstanding bristle but not setulose, the third joint orbicular or oval, the arista bare; no, one or two fronto-orbital bristles, two verticals, ocellars variable in length, interfrontal hairs sparse but usually evident. Mesonotum shining and irregularly covered with fine short hairs except in *P. casei* where they are limited acrostichal and dorsocentral rows. Abdomen depressed oval or elliptical, with five visible segments, male genitalia forming a blunt termination to the abdomen, the penis sometimes exserted when it is long slender and curled. Legs simple, the front femora with a few projecting flexor bristles. Wings without subapical spot, anal vein evanescent

at the end; calypteres and fringe relatively well developed and white in color.

This is the dominant genus of the family. The species act as scavengers and are commonly met with around carrion, offal, garbage, decomposing fungi, etc.

Piophila and *Tyrophaga* were both established on the species *casei* Linneus; *Stearibia* on the species *foveolata* Meigen.

TABLE OF THE NORTH AMERICAN SPECIES OF PIOPHILA

1. Black species, more or less polished. 2.
   Reddish, subopaque, pruinose species; last two sections of costa subequal, veins yellow, anal vein thick, abruptly stopping before margin of wing; front femora pale, setose beneath. **concolor** Thomson
2. Pubescence of head and abdomen black. 3
   Pubesence of head and abdomen gray; front femora black, the middle ones yellow at base, tibiae yellow, tarsi black; face, front, antennae and palpi black; second segment of abdomen with polished hind margin. **senescens,** n. n.
3. Costal cell and apex of wing blackish; legs entirely yellow except at end of tarsi; cheeks, face and front anteriorly, antennae and the broad palpi yellow; clypeus black; pubescence of body short but rather dense. **liturata,** n. sp.
   Wings uniformly hyaline; legs with more or less of dark coloring. 4.
4. Pile of thorax not dense, of abdomen very short and sparse; halteres white or at most with a black spot. 5.
   Thorax and abdomen covered with dense short pile; abdomen ♂ with long pile posteriorly; veins dark and strong; halteres brown; antennæ black. 17.
5. Front not foveolate anteriorly; antennæ usually more or less yellow; either the anterior crossvein beyond the end of the first vein or the last section of the fourth vein distinctly less than twice the preceding. 6.
   Front foveolate anteriorly; head including antennae and proboscis entirely black; anterior crossvein located beneath end of first vein, ultimate section of fourth vein twice as long as penultimate. **nitens,** n. n.
6. Mesonotum shining black, polished and uniformly pubescent; ocellar bristles approximated and inserted behind the front ocellus; abdomen oval. 7.
   Mesonotum aciculate, not pubescent but bearing setulae in three

longitudinal rows; front bare and becoming reddish toward antennæ, face reddish, cheeks wide; ocellar bristles distant from each other and on a level with front ocellus; discal cell wide and anterior crossvein short; abdomen elliptical. **casei** Linnaeus

7. Scutellum convex and smooth; front more or less yellow, red, brown or rarely black, and furnished with scattering hairs; penis thin and not fringed as far as known. 8

Scutellum flattened and microscopically roughened; front entirely black and nearly or quite devoid of pubescence; veins thin and pale; occiput polished; penis thick and densely fringed. **nigriceps** Meigen

8. Front coxae largely or wholly yellow; clypeus and usually oral margin and cheeks yellowish or at most brown; palpi yellow; anterior part of front distinctly yellowish. 9.

Coxae entirely black, if rarely the front coxae yellowish then the face and cheeks are entirely black; anterior part of front more indefinitely brownish. 14.

9. Bristles of head not very strongly developed; orbital and propleural bristles either very weak or entirely absent; lower occiput pruinose; propleuræ pollinose. 10.

Bristles of head strongly developed, two orbital bristles present, the anterior weak, the posterior strong; lower occiput shining. 12.

10. Posterior legs usually yellow; front largely yellow; cheeks broad, more than one-third width of eye; basal joint of arista brown; hairs of ♂ abdomen sparse. **pusilla** Meigen

Femora largely black; upper part of front black; cheeks narrow, less than one-fourth width of eye; arista black; hairs of ♂ abdomen relatively long and dense. (**affinis** Meigen) 11.

11. Halteres yellow. var. **affinis** Meigen

Knob of halteres with a conspicuous black spot. var. **halterata,** n. var.

12. Propleurae shining, the bristle minute; cheeks less than one-third eye-height; arista black; legs yellow, the front femora and end of tarsi sometimes browned. **xanthopoda,** n. sp.

Propleurae pollinose, the bristle strong; cheeks more than one-third eye-height; first joint of arista brown. 13.

13. Front legs black except coxae and knees, posterior femora mostly black; setulae of abdomen sparse as usual. **oriens,** n. sp.

Legs principally yellow, the front femora more or less brownish; sturdy, bristly species with relatively abundant setulae. **setosa,** n. sp.

14. Mouthparts, cheeks, face, half of front and antennae yellowish;

femora black except knees, front tibiae blackish, their tarsi black. **nigricoxa,** n. sp.

Proboscis, palpi, clypeus and usually oral margin and cheeks black. 15.

15\. Propleurae and lower occiput pruinose; antennae and arista uniformly blackish; knob of halteres with blackened tip; legs almost entirely black. **occipitalis,** n. sp.

Body including propleurae highly polished, lower occiput shining; antennæ mostly yellow, the base of the arista brown; halteres yellow. 16.

16\. Posterior femora and all the tibiae yellow, front metatarsi merging in color with the remaining joints; front more or less brown toward antennae. **nitidissima,** n. sp.

All femora black except narrowly at knees, first joint of front tarsi yellow, sharply contrasting with the black remainder; front entirely black. **atrifrons,** n. sp.

17\. Length 3 mm.; front with narrow reddish fascia just behind antennae, face reddish, occiput cinereous pollinose; legs black except knees. **pilosa** Staeger

Length 5 mm.; head and legs entirely black. **nigerrima** Lundbeck

Piophila liturata, sp. nov.

Vertex and entire occiput shining black; vertical and postvertical bristles long and stout, one very weak pair of vertical bristles present; front hairy, the lower part yellow, the upper part black; face, cheeks and the broad palpi yellow, clypeus black, proboscis brownish, cheeks one-third the eye-height; antennæ yellowish, the third joint large and orbicular, the arista with brown root. Thorax entirely black, polished; hairs of notum rather short and dense; prothoracic bristle very weak or entirely absent; scutellum convex. Legs including the coxæ entirely yellow except the black tips of the tarsi. Abdomen elliptical in outline, black but not polished, covered with dense pubescence. Costal cell, costa and the apex of the wing including the veins blackish, veins elsewhere brownish; first vein ending at two-fifths the wing-length, sections of the fourth vein proportioned 3 : 2 : 3, of the fifth vein 7 : 1, anal vein almost reaching the margin. Halteres white.

Length 3 mm.

Five specimens. Avon, Potlatch and Chatcolet, Idaho; Kamiac Butte, near Palouse, Washington (Melander).

Piophila pusilla Meigen

Meigen, Syst. Beschr. Zwfl. Ins., VII. 360 (1838)
Zetterstedt, Dipt. Scand., VI. 2514 (1847)
Schiner, Faun. Austr. Dipt., II. 186 (1864)
Rondani, Bull. Soc. Entom. Ital., VI. 249 (1874)

Vertex and occiput black; vertical and postvertical bristles not very strong; one weak fronto-orbital bristle present; front hairy, variable in width and color but usually one-third the width of the head and yellow except sometimes toward the vertex; cheeks yellow, much broader behind, at the vibrissæ about one-third the eye-height, the pruinosity of the occiput ending abruptly in a vertical line at the cheeks; antennæ small, yellow, the second joint with a weak dorsal bristle, the third joint short, oval, with fuscous arista blackened apically; oral vibrissæ moderately long and stout, the other oral bristles fairly well developed; proboscis and palpi yellow. Notum covered with numerous fine setulæ, black and polished; pleuræ black, sometimes with a reddish tinge, polished; meso- and sternopleuræ bearing a few fine hairs; one weak propleural bristle present on the pruinose pectus; scutellum convex. Front coxæ yellow, front femora with four flexor bristles, yellow at the base, otherwise black except the narrow knee, front tibiæ blackish, front tarsi usually black; middle and hind legs typically yellow, but sometimes blackened. Abdomen shining black, sparsely hairy in both sexes. Wings hyaline, veins pale, the anterior crossvein slightly beyond the middle of the discal cell, last section of the fifth vein two-thirds as long as the posterior crossvein, anal vein terminating a short distance before the margin of the wing.

Length 3 to 3.5 mm.

The species has hitherto not been recorded from America. Seventeen specimens, compared with European material, are before us from the following localities: **Massachusetts**, New Bedford (Hough), Woods Hole, Boston (Melander); **New York**, Cold Spring Harbor (Melander); **Illinois**, Chicago (Melander); **Texas**, Austin (Melander); **Wyoming**, Sheridan (Metz); **Washington**, Pullman (Yothers), Colfax (Melander); **British Columbia**, Nelson (Melander).

Piophila affinis Meigen

Meigen, Syst. Beschr. Zwfl. Ins., VI. 383 (1830) Europe
Zetterstedt, Dipt. Scand., VI. 2511 (1847) Europe
Schiner, Faun. Austr. Dipt., II. 186 (1864) Europe

Lundbeck, Vidensk. Medd. Dipt. Groenl., II. 299, fig. (1900) Greenland

casei Stæger, Groenl. Antl. Kröjer's Tidskr., I. 368 (1845) Greenland

pilosa Holmgren, Oefvers. Kgl. Vetensk. Akad. Förh., XXIX. 104 (1872) Greenland

pygmæa Zetterstedt, Ins. Lapp. Dipt., 772 (1838)

vulgaris Fallen, Dipt. Suec. Heteromyz., 9 (1820)

Var. **nigrifrons** Strobl. Mitt. Ver. Steiermark, 46, 45 (1912)

Vertex and occiput shining black, the lower occipital orbits pruinose; vertical and postvertical bristles well developed; front hairy, yellow except the black upper part; antennæ small, yellow, the third joint rounded, yellow to fuscous, the arista black; oral vibrissæ long and stout, the other oral bristles weak; proboscis fuscous, palpi yellow; fronto-orbital bristles very weak or entirely absent; cheeks narrow in front, at the vibrissæ less than one-fourth the width of the eye, yellow to brownish. Entire thorax black, polished, and with a bluish reflection, the pectus pruinose, notum irregularly covered with fine setulæ, scutellum convex, prothoracic bristle very weak. Front coxæ largely or wholly yellow; front legs black except the tip of the femora and the base of the tibiæ; middle and hind coxæ, tibiæ and tarsi yellowish; middle and hind femora black or blackish except the tip. Hairs of the male abdomen abundant, of the female sparse. Wings hyaline throughout, veins pale brown, anterior crossvein at the middle of the discal cell, last section of the fifth vein two-thirds as long as the posterior crossvein, anal vein almost reaching the outer margin of the wing; halteres yellow.

Length 3 to 3.5 mm.

Ten specimens are in the collection from: **Austria**, Admont (Strobl); **Massachusetts**, Boston, Greenfield (Melander); **Ontario**, London (Hough Coll.); **Washington**, Pullman, Tacoma, Bellingham (Melander).

Piophila affinis, var. halterata, var. nov.

A specimen from Tacoma, Washington (Melander) has the halteres conspicuously tipped with black. It is regarded as a distinct variety since the halteres do not vary in color in this genus and is here named var. *halterata*, var. nov.

Piophilia flavipes, sp. nov.

Occiput subshining black but not pollinose; front black on vertex, upper orbits and ocellar triangle, elsewhere reddish, posterior fonto-orbital bristles quite strong, the anterior ones minute, frontal setulæ relatively abundant; face and cheeks reddish, vibrissæ strong, other oral hairs weak; antennæ reddish, the third joint orbicular, slightly brownish above, the arista black; proboscis and clypeus blackish, palpi yellow. Thorax highly polished, including the propleuræ, notum closely and finely hairy, mesopleuræ bare, scutellum convex though flattened and margined at extreme lateral angles. Abdomen oval, polished, conspicuously black setulose, some of the marginal setulæ, especially of the third segment, quite bristle-like; male genitalia small. Legs entirely yellow except the last four joints of the front tarsi and the last two joints of the posterior tarsi which are black, outstanding flexor bristles of the front femora irregular, only the penultimate one setiform. Wings entirely hyaline, veins yellowish brown, anterior crossvein only slightly beyond the middle of the discal cell, last section of the fifth vein one-seventh the preceding, anal vein evanescent toward the margin.

Length 3 mm.

Five specimens. Lake McDonald, Glacier National Park, Montana, August, 1916 (Melander); Troy, Idaho (Mann).

Piophila oriens, sp. nov.

Black bristly species with dark legs. Occiput subshining black, vertex, ocellar triangle and upper orbits black, front, face, cheeks, antennæ and palpi yellowish, proboscis and sometimes clypeus black, arista blackish, its first joint brown; cheeks broad, more than one-half the eye-height, not pollinose, oral hairs minute, the vibrissæ strong; vertical, postvertical, ocellar and hind fronto-orbital bristles strong, anterior fronto-orbital small, interfrontal hairs present. Mesonotum polished black with a blue tinge, closely hairy, scutellum subconvex, pleuræ polished, the proplueræ sericeous, prothoracic bristles strong. Abdomen broadly oval, shining, rather sparsely hairy, the apical hairs not lengthened. Legs yellowish as follows, elsewhere black, front coxæ, all trochanters, extreme ends of all femora, base of front tibiæ, all of middle tibiæ, basal half of hind tibiæ, middle tarsi and hind tarsi except last joint; flexor bristles of front femora strong, setulæ of legs dense. Wings entirely hyaline,

veins yellowish-brown, sections of the fourth vein proportioned 4 : 3 : 5, of the fifth vein, 7 : 1, anal vein evanescent about midway to the margin. Halteres entirely yellow.

Length 3 mm.

Two males and two females. Ithaca and Geneva, New York, May; Greenfield, Massachusetts, June (Melander).

Piophila setosa, sp. nov.

Bristles of the head strong, the two pairs of verticals, the postverticals and one pair of fronto-orbitals very well developed, the anterior pair of fronto-orbitals much weaker, front hairy, cheeks broad, nearly half the eye-height, front and cheeks yellow, the black of the occiput extending forward on the ocellar triangle and vertical orbits, the upper occiput pollinose; vibrissæ long and stout, the other oral bristles developed in several rows; antennæ yellow, the third joint round, the first joint of the arista brown. Mesonotum shining, covered with dense irregular setulæ, metanotum uniformly subshining; pleuræ piceous, propleuræ pruinose, the bristle well developed, hairs of the sternopleuræ and coxæ long. Legs robust, hairy, the front femora with about six bristles underneath, all the legs yellow except the black tips of the front tarsi, the front femora sometimes brownish except at the extremities. Abdomen oval, depressed, reddish, its hairs rather sparse. Wings hyaline, veins heavy, yellow, anterior crossvein at or a little beyond the middle of the discal cell, posterior crossvein slightly longer than the last section of the fifth vein, anal vein nearly reaching the margin of the wing.

Length 3 mm.

Six specimens, Douglas, Alaska, August 1-12, 1901 (Jenne).

Piophila nigricoxa, sp. nov.

Vertex and upper occiput shining black, lower occiput with a pruinose stripe; vertical and postvertical bristles long and stout; fronto-orbital bristles entirely absent or very weak, the front irregularly provided with sparse black hairs, its upper half black, its lower half yellow; antennæ yellow, arista black; face and cheeks yellow, the cheeks hairy, especially wide behind, averaging one-third of the eye-height; proboscis brownish, palpi large, yellowish; oral vibrissæ prominent, the hairs of the cheek distinct. Thorax polished black with a bluish lustre; notum covered with fine setulæ; pro-

pleuræ white-pollinose, prothoracic bristle weak, scutellum slightly convex, metanotum uniformly subshining. Front coxæ black, front femora black except the tip which is yellow, with some outstanding hairs; front tibiæ blackish, their tarsi varying from black (♀) to yellow (♂), middle and hind coxæ yellow, middle and hind femora black, their tibiæ and tarsi yellow. Abdomen depressed, blue-black, the hairs fairly numerous, especially in the male, the last tergite of the male finely transversely rugulose, the curled yellow penis not fringed. Wings entirely hyaline, veins light brownish, anterior crossvein at the middle of the discal cell, posterior crossvein twice as long as the last section of the fifth vein, anal vein evanescent.

Length 4 mm.

Five males, five females; Pullman, Walla Walla, Washington; Moscow Mountain, Idaho; Flathead Lake, Montana, (Melander).

Piophila occipitalis, sp. nov.

Vertex and upper occiput shining black, sides of the occiput with a vertical pruinose stripe; vertical bristles strong, postverticals weak, fronto-orbitals absent; front dark brown anteriorly, merging into the black vertex, covered with sparse short black hairs; antennæ covered with a white velvety pubescence, in ground color entirely blackish; cheeks about one-third the eye-height, not greatly deeper behind, in color black, oral vibrissæ moderately stout, the other oral bristles weak; proboscis black, palpi blackish. Thorax jet black, propleuræ sericeous, metanotum scarcely dusted, mesonotum covered with numerous fine hairs, scutellum convex. Front coxæ yellow, front femora, tibiæ and the basal joints of the tarsi black; apical joints of the tarsi fuscous; posterior legs black except the coxæ and the tarsi which are yellowish. Abdomen black, covered with fine black hairs, depressed and broadly truncate apically, the penis simple and rather thick. Wings hyaline throughout, veins heavy, coarse and brownish, anterior crossvein at the middle of the discal cell, posterior crossvein slightly longer than the last section of the fifth vein, last section of the fourth vein curving slightly forward at the middle, anal vein evanescent before the margin of the wing.

Length 3 mm.

Two males, Chicago, Illinois (Melander).

Piophila nitidissima, sp. nov.

Head shining black except the yellow antennæ and the reddish tinge to the lower portion of the front; bristles of the head rather weakly developed; orbital bristles very weak or entirely absent; oral vibrissæ moderately long, the other oral hairs weak, cheek about one-third the eye-height, not much deeper behind. Thorax shining black throughout, notum irregularly hairy, scutellum convex, metanotum and propleuræ not dusted. Front legs with the coxæ and femora black, the tibiæ and tarsi yellow excepting the blackened tip to the tarsi; posterior legs entirely yellow. Abdomen depressed oval, shining black, its hairs sparse. Wings hyaline, veins yellowish, anterior crossvein short and located beyond the middle of the discal cell, posterior crossvein almost twice as long as the last section of the fifth vein.

Length 2 to 3 mm.

Two males, ten females. **Idaho** Moscow Mountain and Coeur d'Alene (Melander), Moore's Lake (Aldrich); **Washington**, Pullman (Yothers); **California**, Yosemite (Cresson).

Piophila atrifrons, sp. nov.

Female. Head entirely black, shining, no orbital pollen; front with a few scattered minute hairs, no fronto-orbital bristles; antennæ brown, the third joint circular, the arista black; cheeks one-third the eye-height, scarcely deeper posteriorly, vibrissæ long, oral hairs conspicuous; proboscis and palpi black. Thorax shining black, with scattered notal hairs, scutellum convex and smooth, propleuræ shining, no prothoracic bristle, mesopleuræ glabrous. Abdomen oval, polished, the small hairs sparse. Coxæ, trochanters, femora except at tip and last four joints of front tarsi black, the remainder of the legs yellow, three strong flexor bristles on the front femora. Wings entirely hyaline, veins pale yellow, anterior crossvein at three-fifths the length of the discal cell, anal vein almost abruptly ending midway toward the margin.

Length 3 mm.

Three specimens from Oroville, Washington (Melander) and Troy, Idaho (Mann).

Piophila nigriceps Meigen

Meigen, Syst. Beschr. zwfl. Ins., V. 397 (1826) Europe
v. Roser, Württemb. Correspbl., 60 (1840) *Psila*

Zetterstedt, Dipt. Scand., VI. 2516 (1847) Europe
Walker, List Dipt. Ins. Brit. Mus. IV. 1065 (1849) occ. in America
Schiner, Faun. Austr. Dipt., II. 185 (1864) Europe
Loew, Silliman's Am. Jour. Sci. Arts. XXXVII. 317 (1864) occ. in America
Rondani, Bull. Soc. Ital., VI, 250 (1874) Europe
Strobl, Wein. Ent. Ztg., XII. 126 (1893)
Villeneuve, Wein. Ent. Ztg., XXXII. 128 (1913)

foveolata Meigen, Syst. Beschr. Zwfl. Ins. V. 396, pl. liv. f. 3 (1826)
Macquart, Hist. Nat. Ins. Dipt., II. 543 (1835)
Schiner, Faun. Austr. Dipt., II. 185 (1864)
Rondani, Bull. Soc. Ent. Ital., VI. 249 (1874)
Becker, Zts. Hym. Dipt., II. 248 (1902)

vulgaris Fallen, p. p., Dipt. Suec. Heteromyz , 9 (1820)
Zetterstedt, var., Ins. Lapp., 772 (1838)

Entire head shining black except the yellowish antennæ; vertex, occiput and front smooth; third antennal joint orbicular, the arista red at the base; vertical and postvertical bristles rather long and stout; fronto-orbital bristles very weak or entirely absent, the usual delicate hairs of the front absent; vibrissæ stout, the other oral hairs rather prominent, cheeks less than one-third the eye-height and not enlarged posteriorly; mouthparts including the palpi black. Notum with fine light-colored setulæ, black, polished; pleuræ bare and shining black, the propleuræ white-pollinose, the bristle absent; scutellum flat and finely roughened. Front coxæ yellow to brown, the legs variable in color, sometimes entirely black except the posterior tarsi which are yellow, sometimes the front knees and the posterior tibiæ yellowish. Abdomen broadly oval, shining black, the short vestiture black; penis thick, yellow, furnished with four longitudinal fringes of long yellow hair. Wings hyaline, costa and the first vein slightly browned, the other veins clear, colorless, anterior crossvein short, near or slightly beyond the middle of the discal cell, posterior crossvein twice as long as the last section of the fifth vein, anal vein terminating a short distance before the margin.

Length 2.5 to 3.5 mm.

The species is readily distinguishable by its flat scutellum and entirely black head. Aside from Johnson's notice of the occurrence of *P. nigriceps* in New Jersey there are no definite locality records of this European species in America since Walker noted that it occurred in Canada. We have

over a score of specimens from the following localities. **Europe**, Austria (Strobl); **Ontario**, London, Toronto (Hough Coll.); **Massachusetts**, Woods Hole (Melander); **New Hampshire**, Durham (Randall); **New York**, Cold Spring Harbor (Melander); **Illinois**, Chicago (Melander); **Alabama** (Baker); **Washington**, Pullman, Kamiac Butte (Melander); **British Columbia**, Nelson (Melander).

Piohila casei Linnæus

Linnæus, Fauna Suec., 456 (1761) *Musca*
Fallen, Dipt. Suec. Heteromyz., 9 (1820)
Meigen, Syst. Beschr. zwfl. Ins., V. 395 (1826)
Macquart, Hist. Nat. Dipt., II. 541 (1835)
Bouche, Naturgesch. d. Ins., 99 (1837)
Zetterstedt, Ins. Lapp., 772 (1838)
Germar, Stettin. Ent. Ztg., 1841, 126 (1841)
Dufour, Ann. Sci. Natur., 1844, 365 (1844)
Dahlbom, Skan. Ins., 323, pl. ii. f. 24 (1847)
Zetterstedt, Dipt. Ins., Scand., VI. 2510 (1847)
Walker, Ins. Brit. Dipt., II. 222 (1853)
Wallaston, Ann. Mag. Nat. Hist., 1858, 261 (1858)
Schiner, Faun. Austr. Dipt., II. 186 (1864)
Loew, Silliman's Am. Jour. Sci. Arts, XXXVII. 317 (1864) North America.
Walker, Entomologist, 92. 346 (1871)
Faulconnier, Bull. Soc. Ent. Fr., 1865, pp. lxviii, lxix (1865)
Goureau, Insectes nuisables, 184-187 (1867)
Rondani, Bull. Soc. Ent. Ital., VI. 249 (1874)
Willard, Am. Entom., II. 78 (1870)
........, Am. Ent., III. 23, 24 (1880)
Kessler, Ber. Ver. Naturk. Cassel, XXIX-XXX. 58-60 (1883)
Lundbeck, Vidensk. Medd., 1890, 299 (1890)
Kellogg, Kans. Acd. Sci., XIII. 112 (1892); Ins. Life, V. 116 (1892)
Murtfeldt, Ins. Life, V. 135 (1892); VI. 170-175 (1893)
Riley and Howard, Ins. Life, VI. 208 (1893)
Murtfeldt, Rep. Ent. Soc. Ont., XXIV. 98-102 (1893)
Howard, Bull. U. S. Bur. Ent., IV. 102 (1896)
Lintner, Rept. N. Y. Ent., XII. 229-234, figs. (1897)
Motter, Jour. N. Y. Ent. Soc., VI. 223 (1898)
Howard, Proc. Wash. Acad. Sci., II. 588, pl. xxx. figs. (1900)
Becker, Zts. Hym. Dipt., II. 247 (1902)
Krausse, Zts. Wiss. Insektenbiol., V. 394-398 (1909)
Alessandrini, Arch. Parasitol., XIII. 337-382, figs. (1910)
Banks, Science, Oct. 14, 1910, 517 (1910)

Johnson, Ins. N. J. Dipt., 804, f. 334 (1910)
Howard, Housefly, 249-251 (1911)
Austin, 66 Rept. Govt. Bd. Publ. Health, 5-15 (1912)
Ruhl, Soc. Entomol., XXVII. 15 (1912)
Herrick, Ins. Inj. to Household, 288-292, figs. (1914)
Graham-Smith, Flies and Disease, 37, pl. vii. figs (1914)
Mote, Ohio Naturalist, XIV. 309-315, pl. xiv. (1914)

affinis Zetterstedt (not Meigen), Dipt. Scand., VI. 2511 (1847)

atrata Fabricius, Spec. Ins., II. 333 (1781) *Musca;* Syst. Antl. 323 (1805) *Tephritis*
Meigen, Syst. Beschr. zwfl. Ins., V. 396 (1826)
Macquart, Hist. Nat. Ins. Dipt., II. 542 (1835)
Zetterstedt, Ins. Lapp., 772 (1838); Dipt. Scand., VI. 2511 (1847)

melanocera Rondani, Bull. Soc. Ent. Ital., VI. 249 (1874)

petasionis Dufour, Ann. Sci. Nat., 1844, 369, pl. xvi. f. 7 (1844)
Loew, Silliman's Jour. Sci. Arts, XXXVII. 317 (1864) America

putris Kessler, Ber. Ver. Naturk. Cassel, XXIX.-XXX. 58-60 (1883) *Tephritis*

vulgaris Fallen, p. p., Dipt. Suec. Heterom., 9 (1820)

Head black above, the front sericeous except for the large ocellar triangle, toward the antennæ narrowly yellow; occiput finely roughened, polished, the lower occipital orbits narrowly pruinose; face, cheeks, mouth parts and antennæ yellow, the cheeks greatly broadened behind, vibrissæ prominent, oral hairs weak or absent; third joint of the antennæ short, oval, the arista brown. Notum black, with faint ænescent tinge, not smoothly polished but minutely roughened, bearing three rows of fine setulæ in lieu of the irregularly scattered hairs of the other species of *Piophila;* mesopleuræ with scattered minute hairs, propleuræ pollinose, the bristle evident; scutellum convex. Abdomen more oblong than usual, the black pubescence conspicuously long. Legs largely black and hairy, coxæ, trochanters, knees and posterior tarsi more or less yellow. Wings hyaline, veins pale, anterior crossvein shorter than usual but variable, located beyond the middle of the widened discal cell, basal cells indefinitely wider than usual, anal vein evanescent some distance before the margin.

Length 2.5 to 4 mm.

This almost cosmopolitan species is widely distributed over North America. Like the others it is variable in color and has been described under several specific names, some

of which *(atrata, petasionis, vulgaris* and *putris)* have definitely been assigned to synonomy, while others *(affinis, melanocera)* are less surely the same.

The species has previously been recorded in North America from Greenland and Alaska to the West Indies and New Mexico. We have 67 specimens as follows: Europe, England (Brunetti); **Jamaica**, Kingston (Johnson); **Pennsylvania**, Philadelphia (Cresson); **Wisconsin**, Polk County (Baker); **Louisiana**, Opelousas (Hough Coll.); **Texas**, Austin, (Melander); **Kansas**, Lawrence (Aldrich); **South Dakota**, Brookings (Aldrich); **Idaho**, Moscow (Aldrich); **Washington**, Pullman, Wenatchee, Tacoma (Melander).

The species in its larval instars is known commonly as the cheese skipper. It breeds not only in cheese but also in rotten fungi and dead adipose tissue, such as of cadavers, or in the fat of ham or bacon. It is also a frequent visitor about garbage accumulations. When taken into the alimentary tract during its early stages it may continue its development, producing a form of enteric myiasis, and in the dog causes lesions of the intestines by its presence. Austin reports a nasal myiasis also. The maggots, which sometimes occur by thousands in decomposing animal matter, have the power of springing by bending the two ends of the body together and then suddenly straightening. The species moreover is not infrequently found in houses and is attracted to windows. The last nineteen references deal with the biology of the cheese or ham skipper.

Piophila nitens, nom. nov.

nitida Wulp (not Brule, 1832), Tijdschr. v. Ent., X. 160, pl. v. f. 16-18 (1867)

Female. Shining black; abdomen slightly metallic; head including the antennæ black; front anteriorly foveolate; legs black, knees and base of tarsi yellow; halteres white.

Front with a crescentic impression above antennæ, which is bounded behind by a ridge, behind which the front is again impressed; vertical bristles weak; the face short, oral bristles weak; proboscis entirely black; wings almost hyaline; veins yellow basally, becoming yellowish distally, anterior

crossvein located beneath the end of the first vein; ultimate section of the fourth vein twice as long as the penultimate. (Translation).

Length 2.7 mm. Wisconsin.

This species is not represented in the collection. It is apparently very distinct in the conformation of the front, in which character it seems to approach the variety *foveolata* of *P. nigriceps*. The salient points of Mr. Wulp's description are given above and suggest the genus *Pseudodinia* Coquillett.

Piophila pilosa Stæger

Stæger, Groenl. Antl. Krojer's Tidskr., 1, IV. 368 (1845)
Zetterstedt, Dipt. Scand., VI. 2514 (1847)
Lundbeck Dipt. Groenl., Vidensk. Medd., 301 (1900)

Black shining, with short dense hairs over the entire body, especially in the male. Face and a narrow anterior frontal vitta reddish; antennæ wholly black; occiput cinereous pollinose. End of the male abdomen hairy, incrassate and incurved; abdomen of the female sparsely hairy. Legs black with reddish knees. Wings hyaline, the veins strong and brown.

Length, 3 mm. (Paraphrased translation from Stæger and Lundbeck)..

Habitat: West Coast of Greenland.

Piophila nigerrima Lundbeck

Lundbeck, Dipt. Groenl., Vidensk. Medd. naturh. Foren. Kbn., 301, f. 3 (1900)

Male. Black, shining, thorax densely and briefly hairy, abdomen ovate, with long pile expecially toward the margin. Antennæ, front, face and mouth parts black. Wings grayish, the veins blackish brown. Halteres brown. Legs black, the knees slightly reddish, the front femora with long hairs.

Length about 5 mm.

This species is distinct by its large size and wholly black color. (Translation).

Habitat: Greenland.

It is not impossible that this is the same species as *P. pilosa* Stæger.

Piophila senescens, nom. nov.

nigriceps Macquart (not Meigen), Dipt. Exot. Suppl., IV. 276 pl. 28, f. 6 (1851)

Female. Black, the thorax shining. Abdomen gray-pubescent. Femora black, with reddish base; tibiæ red, tarsi black. Palpi black. Face and front black, with sparse fine gray hairs. Antennæ black. Thorax and scutellum shining. Abdomen black, with fine gray hairs, the posterior edge of the second segment polished. Front femora black, middle femora black but with yellowish base; hind legs wanting; tibiæ yellowish, tarsi black. Halteres yellow. Wings hyaline, with yellowish base.

Length 3 mm. (Translation).

Vaguely recorded from North America. The species differs from the others in having gray pubescence. It may not be a *Piophila* at all. Macquart's figure shows a distinct auxiliary vein, but as his other figures are not trustworthy he may have erred in this detail.

Piophila concolor Thomson

Thomson, Eugenies Resa, Dipt., 596 (1868)

Rufo-testaceous, subopaque, pruinose; wings oblong, the last section of the costa almost longer than the submarginal, anterior crossvein a little beyond the end of the first vein.

Head sub-rounded, red; front flat, with three setæ; face short, vertical, constricted at the middle, with strong vibrissæ, cheeks not broad; peristome broad, narrower in front; proboscis not strong; eyes nearly rotund, the lower margin subsinuate in back, frontal orbits anteriorly somewhat convergent, the facial strongly divergent. Thorax subopaque, dorsal bristles distinct in back and at the sides; scutellum small with four bristles; wings twice as long as the abdomen, irridescent, veins yellow, submarginal section of the costa almost shorter than the last section; postcosta attaining the anterior third of the wing; submarginal section of the cubital running out at the very tip of the wing; anal vein thick, abruptly stopping before the hind margin; anterior crossvein somewhat beyond the end of the postcostal, before the middle of the wing, and almost before the middle of the discal cell; anal cell distinct; lobe not broad; halteres whitish yellow, the club triangular. Abdomen oblong, yellowish. Legs elongate, slender, front coxæ rather long, scarcely exceeding the middle of the mesosternum; front femora rather

thick, pale setose beneath; tibiæ unarmed, tarsi elongate, claws and pulvilli small; mesosternum above with two setæ, pleural suture not setose. (Translation).

Length 4 mm.

California.

Genus **MYCETAULUS** Loew

Loew, Dipterol. Beitr., I. 37 (1845)
Schiner, Faun. Austr. Dipt., II. 187 (1864)

Brachygaster Meigen, Syst. Beschr. zwfl. Ins., V. 244 (1826) (not Leach, Crustacea, 1817)

Head flattened at the occiput; face flat; two pairs of vertical bristles, two of orbital bristles, the posterior long and strong, the anterior smaller; antennæ small, the third joint short, oval, the arista long, hairlike and bare; face depressed beneath the antennæ, nearly vertical; vibrissæ prominent, cheeks narrow, palpi upturned, beneath with a few hairs and a preapical seta. Mesonotal hairs abundant, two pairs of dorsocentral bristles, four scutellars, two sternopleurals, two notopleurals, one presutural, one humeral. Legs of the male simple, front femora with two preapical flexor bristles. Abdomen not constricted at the second segment, broad, with five visible segments; genitalia of the male not hidden; ovipositor short but extensile. Wings with a brown spot at the tip of the first vein and another at the end of the second vein, the first vein short, ending within the basal third of the wing, anal vein evanescent.

Genotype, *M. bipunctatus,* described by Loew as *Hoffmeisteri.* Meigen (Syst. Bes., V. 244 and 245) incidentally states that Megerle sent him the species *analis* and *varia* under the name of *Brachygaster.* Hence he has been credited with the creation of this generic name. The American species of *Mycetaulus* are separable as follows:

Wings three times as long as broad; entire head and thorax reddish. **bipunctatus** Fallen

Wings relatively longer and narrower; occiput brownish; pectus metanotum and anterior spot on the mesonotum blackish. **longipennis** Loew

Mycetaulus bipunctatus Fallen

Fallen, Dipt. Suec. Geomyzid., 3 (1823) *Geomyza*
Meigen, Syst. Beschr. zwfl. Ins., VI. 110 (1830) *Opomyza*
Zetterstedt, Ins. Lapp. Dipt., 773 (1838) *Piophila;* Dipt. Scand., VI. 2522 (1847) *Piophila*
Schiner, Faun. Austr. Dipt., II. 187 (1864)
Becker, Zts. f. Hym. Dipt., II. 308 (1902)
Hoffmeisteri Loew, Dipterol. Beitr., I. 37 (1845)
pulchellus Banks, Proc. Ent. Soc. Wash., XVII. (1915)

Entire head reddish, except sometimes the blackened ocellar area; postvertical and occipital bristles relatively strong; antennæ reddish yellow, the first two joints very small, arista brownish; tip of proboscis black. Thorax reddish throughout, the notum covered with numerous fine setulæ, the lateral bristles long and slender. Front coxæ elongated, bearing a number of long flexor bristles near the apex, light yellow; front femora not at all enlarged, simple, reddish but lighter than the posterior femora; front tibiæ yellowish, posterior ones brownish, tarsi slightly dusky apically. Under side of the abdomen reddish, the tergites dull black, setulæ sparse ♀ or rather dense ♂, tergites with weak marginal bristles. Wings with a large blackish spot more or less triangular in outline, covering the tips of the second and third veins, the costal cell also blackish except toward the base where it becomes yellow, veins blackish, anterior crossvein before the outer third of the discal cell, posterior crossvein about twice as long as the last section of the fifth vein, anal vein almost reaching the margin.

Length 2 to 3 mm.

The species is widely distributed, occurring in Europe and North America. We have over sixty specimens from the following places: **Montana**, Glacier National Park (Melander); **Wyoming**, Sheridan (Metz); **Idaho**, Chatcolet, Collins, Priest Lake, Moscow Mountain (Melander), Troy (Mann); **Washington**, Pullman (Yothers-Melander), Friday Harbor, (Aldrich), Kamiac Butte, Tacoma, Mount Constitution, Bellingham, Dewatto (Melander); **California**, Mountain View (Ehrhorn), Corte Madera (Mann), Berkeley, Muir Woods (Melander).

Banks recently described the species as *M. pulchellus* from Virginia.

Mycetaulus longipennis Loew

Loew, Berlin. Ent. Zts., XVI. 224, Cent. ix. 100 (1872)

Male. Reddish yellow; head of the same color; occiput brownish; antennæ yellow; a spot, which is located at the front margin of the thorax, the pectus, the metanotum and the abdomen entirely black; legs luteous, the base of the posterior tibiæ and the apices of the tarsi dark brown; halteres white; wings hyaline, with the costal cell subfuscous, the subcostal cell very narrowly blackish, and with a blackish apical spot. (Translation).

Hudson Bay, Canada.

A female from Fulton County, Pennsylvania, submitted by C. W. Johnson, has actually narrower and more delicately pointed wings than in *M. bipunctatus,* although the difference is well nigh microscopic. The front is blackish, but the pectus, mesothorax and metathorax are colored as in the other species and are not so blackened as in the northern form. Mr. Johnson reports an additional specimen in the collection of the Boston Society of Natural History from Wolfeboro, New Hampshire.

Genus **SCOTIMYZA** Macquart

Macquart, Hist. Nat. Ins. Dipt. II. 540 (1835)

Body rather slender. Head hemispherical. Proboscis rather thick, labella short. Palpi somewhat inflated with hairs beneath and at apex. Face slightly receding, epistome a little prominent. Third antennal joint oval, the arista tomentose, swollen at the base, its first joint distinct. Eyes round. Thorax with deep transverse groove; scutellum bluntly pointed. Abdomen rather narrow, depressed, setulose, with six distinct segments. All tarsal joints a little lengthened. Auxiliary vein separated from the first vein. (Translation).

Apparently the single species of *Scotimyza* has not been recognized since its discovery years ago near Liege, Belgium. Macquart ranged it with *Piophila* from which it differed by its downy arista.

Genus **RHYNCHÆA** Zetterstedt

Zetterstedt, Dipt. Scand., VI. 2524 (1847)
Schiner, Faun. Austr. Dipt., II. 188 (1864)

Head large, rounded. Front declivous, narrow, with short sparse hairs, the bristles at the vertex. Antennæ incumbent on the face, not attaining the mouth, the third joint oblong, arista bare. Vibrissa single. Proboscis somewhat projecting, swollen; palpi large, rounded. Eyes large, rounded, oblong. Thorax smooth, shining, sparsely hairy. Abdomen ovate, a little depressed, shining, with five segments. Calypteres minute. Crossveins remote, auxiliary vein vestigial. Legs simple. (Paraphrased translation).

The single species of this genus, *R. lonchæoides* Zetterstedt, was discovered near Stockholm, Sweden, in 1834, and apparently has not been found since. It is a small insect, measuring two millimeters, and resembles *Lonchæa*.

Genus **PSEUDOCEPS** Becker

Becker, Zts. f. Hym. Dipt., II. 244 (1902)

Antennæ short, the third joint rounded, arista bare. Vibrissæ delicate; mouthparts ♂ retracted, palpi ♀ compressed, rounded beneath. Mesonotum subshining, with a few short hairs; four scutellar bristles. Legs simple. Wings broadly rounded apically, the third vein curving forward and divergent from the fourth, anal crossvein curving outward.

But a single rare species, *P. signata* Fallen, is known. It occurs in Sweden, measures about two millimeters in length and is dimorphic in the sexes in the structure of the palpi and in the color of the bristles, those of the vertex and scutellum being yellow in the male and black in the female.

ADDENDA

EXTRANEOUS GENERA

The following genera are excluded from the family Sepsidæ, s. lat., although they have at some time or other been assigned there. It is not impossible that some of the genera previously discussed, e. g. Megamerina or Toxopoda, will also find their ultimate location outside of this family.

Genus **MADIZA** Fallen

Fallen, Dipt. Suec. Oscin., 8 (1820)
Schiner, Faun. Austr. Dipt., II. 188 (1864)

Schiner places Madiza in the midst of the Piophiline series of the Sepsidæ. There is no necessity for removing this insect from the Milichiidæ where it finds its true allocation as is shown by such index characters as the double fracture of the base of the costa and the non-divergence of the postvertical bristles. For the relationships of Madiza see Melander, Jour. N. Y. Ent. Soc., XXI. pp. 234-246 (1913).

Genus **MYRMECOMYIA** Desvoidy

Desvoidy, Myodaires, 721, xv. (1830)
Hendel, Gen. Ins., 157, 21 (1914)

Cephalia Meigen (not Panzer, 1805, Hymenoptera), Syst. Beschr. zwfl. Ins., V. 293, pl. xlvii. f. 10-16 (1826)
Schiner, Faun. Austr., II. 176 (1864)

Head rounded, occiput lengthened, face projecting, swollen, antennæ not reaching oral margin, arista bare, vertex broad and with impressions. Two scutellar bristles; abdomen with six segments, slender at the base, first segment of the ovipositor wide and flat. Third and fourth veins parallel.

The genus has for some years been excluded from the Sepsidæ to represent the subfamily Cephaliinæ (Myrme-

comyiinæ) of the Ortalididæ. Genotype, *C. rufipes* Meigen, 1826, redescribed by Desvoidy in 1830 as *M. formicaria.* Williston reports in Trans. Am. Ent. Soc., XIII. 307 that he has taken in Virginia what is apparently the same species. The other North American species are: *C. fenestrata* Coquillett, *C. fulvifrons* Bigot and *C. maculipennis* Bigot.

Genus **Myrmecothea** Hendel

Hendel, Wien. Ent. Ztg., XXIX. 311 (1910); Gen. Ins. 157, 23 (1914)

First longitudinal vein bristly toward end; mesopleural bristle small; abdomen ♀ with five segments; face projecting obliquely forward, antennæ reaching beyond oral margin, arista pubescent, no vibrissæ; no alula. This ant-like fly belongs to the Platystominæ of the Ortalididæ.

North American species, *M. myrmecoides* Loew, described as of the genus Cephalia and later referred to Myrmecomyia.

Genus **SEPSISOMA** Johnson

Johnson, Ent. News, XI. 327 (1900)

Hendel, Deut. Ent. Zts., 1911, 378 (1911); Gen. Ins. 113, 34 (1911)

Michogaster, part, Schiner, Novara, Dipt., 257 (1868)

First vein not bristly; face concave and vertical, shorter than the antennæ; mesopleural bristle present; six abdominal segments; front and hind femora with spinous bristles.

The original species, *S. flavescens,* was located by Johnson in the section Richardina of the Ortalididæ, but Schiner included some Brazilian species of this group in his conception of Michogaster. The only North American species is *S. flavescens,* which is a reddish ant-like Sepsis-like fly occurring in the Eastern States.

Genus **SETELLIA** Desvoidy

Desvoidy, Myodaires, 732 (1830)

Bigot, Ann. Soc. Ent. Fr. (6) VI. 388 (1886)

Hendel, Deut. Ent. Zts., 1911, 195 (1911); Gen. Ins., 113, 12 (1911)

Antineura Williston (not Osten Sacken) Man. N. Am. Dipt., 3 ed., 271, f. 107; 273, f. 19 (1908)

Cephalia Wiedemann (not Meigen), Auss. Zwfl. Ins., II. 469 (1830)

Conopsida Macquart, Dipt. Exot. Suppl., 4, pt. 2, 267 (294) (1851)

Michogaster Macquart, Hist. Nat. Ins. Dipt., II. 483 (1835)

Gerstæcker, Stett. Ent. Zts., XXI. 177 (1860)

Schiner, Reise Novara, Zool. Dipt., 225 (1868)

Loew, Monogr. N. Am. Dipt., III. 22 (1873) *Mischogaster*

Wulp, Biol. C. Am. Dipt., II. 385 (1900) *Mischogaster*

Omalocephala Macquart (not Spinola, 1839), Dipt. Exot. 2, pt. 3, 231 (388) (1843)

Tylemyia Giglio-Tos, Boll. R. Univ. Torino, VIII. no. 158, 14 (1893)

As is evident from the series of synonyms this genus has caused considerable confusion. Most of the known species come from tropical America but apparently are not commonly found.

Femora without spines; abdomen petiolate, bearing an outstanding lateral bristle toward the base; first vein bristly or hairy; no oral vibrissæ; third antennal joint elongate, arista pubescent; ocelli located anteriorly; abdomen with six or seven segments. A full discussion is given by Hendel in the Genera Insectorum, showing the relationships and characters of this Richardiine fly.

Genotype, the original species described by Desvoidy is the unknown *S. afra*, which possibly may be *S. fascipennis* Wiedemann or *S. diffusa* Gerstäcker. The North American species are the following: *Mischogaster nitidipennis* Wulp, *Omalocephala fusca* Macquart, *Setellia apex* Hendel and *Setellia micans* Hendel. All are from Mexico or Central America.

EXPLANATION OF PLATE

Fig. 1. *Piophila casei* Linnæus, dorsal aspect (from Graham-Smith).

Fig. 2. *Sepsis violacea* Meigen, dorsal aspect (from Howard).

Fig. 3. *Sepsis violacea* Meigen, pupa (from Howard).

Fig. 4. *Meroplius stercorarius* Desvoidy, profile (from Howard).

Fig. 5. *Sepsis insularis* Williston, front leg of male.

Fig. 6. *Sepsis armillata,* n. sp. front leg of male.

Fig. 7. *Sepsis discolor* Bigot, front leg of male.

Fig. 8. *Sepsis violacea* Meigen, front leg of male.

Fig. 9. *Sepsis luteipes,* n. sp., front leg of male.

Fig. 10. *Sepsis curvitibia,* n. sp., front leg of male.

Fig. 11. *Sepsis furcata,* n. sp., front leg of male.

Fig. 12. *Sepsis hoplicnema,* n. sp., front leg of male.

Fig. 13. *Sepsis pectoralis* Macquart, front leg of male.

Fig. 14. *Sepsis pyrrhosoma,* n. sp., front leg of male.

Fig. 15. *Sepsis punctum* Fabricius, European, front leg of male.

Fig. 16. *Sepsis hecate,* n. sp., front leg of male.

Fig. 17. *Sepsis neocynipsea,* n. sp., front leg of male.

Fig. 18. *Sepsis vicaria* Walker, front leg of male.

Fig. 19. *Sepsis signifera,* n. sp., front leg of male.

Fig. 20. *Sepsis cynipsea* Linnæus, European, front leg of male.

Fig. 21. *Sepsis incisa* Strobl, European, front leg of male.

Fig. 22. *Pandora scutellaris* Fallen, front leg of male.

Fig. 23. *Themira latitarsata,* n. sp., front leg of male.

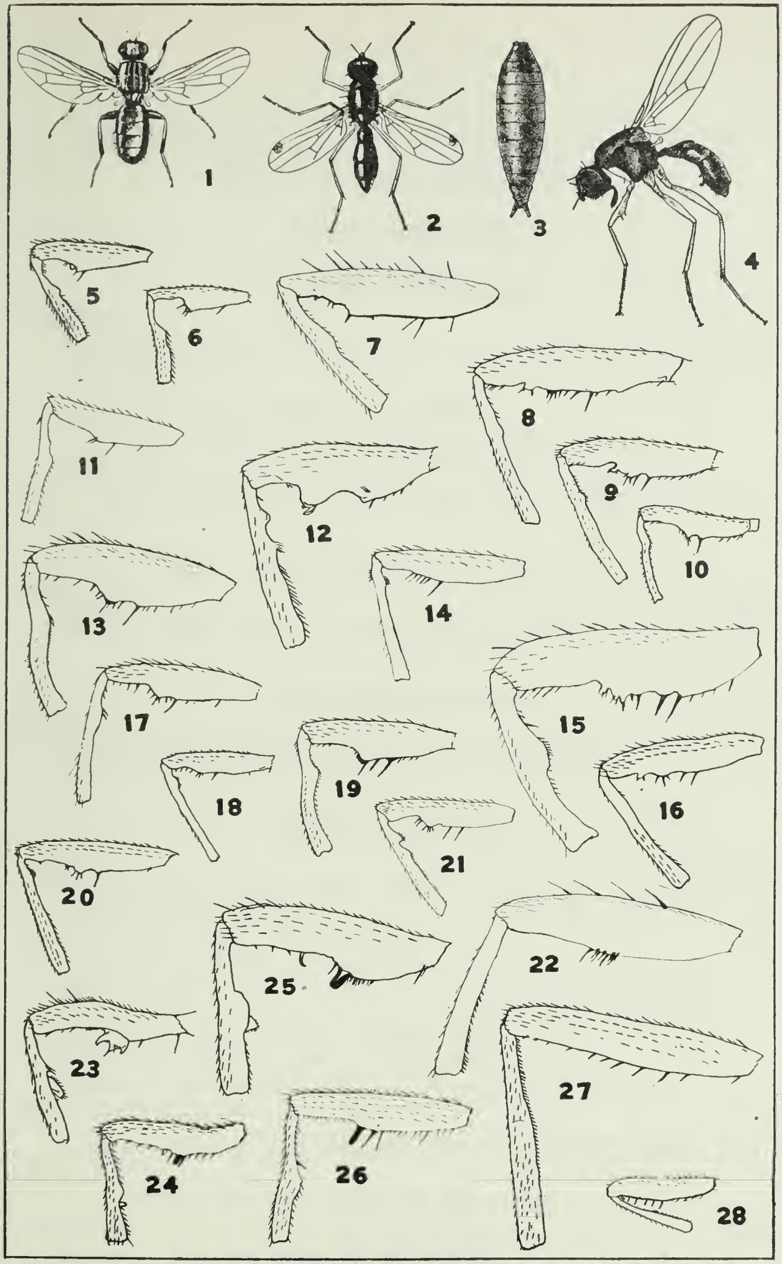
Fig. 24. *Themira minor* Haliday, front leg of male.

Fig. 25. *Themira putris* Linnæus, front leg of male.

Fig. 26. *Meroplius stercorarius* Desvoidy, front leg of male.

Fig. 27. *Nemopoda cylindrica* Fabricius, front leg of male.

Fig. 28. *Sepsidimorpha secunda,* n. sp., front leg of male.



MODIFICATIONS OF FEMORA AND TIBIAE OF VARIOUS
SPECIES OF SEPSIDAE

BIBLIOGRAPHY OF THE DESCRIBED SPECIES OF SEPSIDÆ AND PIOPHILIDÆ

Family SEPSIDÆ

Amphipogon Wahlberg

spectrum N. Eur.; Alps

Wahlberg, Oefvers. af Kong. Vet. Akad. Föhr., X. 217, pl. iv. (1844)

Boheman, Entom. Arsber., 198 (1844)

Zetterstedt, Dipt. Scand., VII. 2685 (1848)

Mik, Vehr. z. b. Ges. Wien., XXVIII. 473-476, fig. (1878)

flava Zetterstedt, Ins. Lapp., 784, ♀ not ♂ (1838) *Macrochira*

Amydrosoma Becker

discedens Egypt

Becker, Mitth. Zool. Mus. Berlin, II. 141, pl. iv. e, fig. 69 (1903)

Centrioncus Speiser

prodiopsis S. E. Africa

Speiser, Kilimandjaro-Meru Exp. X. 5, 191 (1910)

Enicita Westwood

annulipes Europe

Meigen, Syst. Beschr. Zwfl. Ins., V. 292 (1826) *Sepsis;* VII. 350 (1838) *Nemopoda*

Curtis, Brit. Ent., 245 (1833) *Enicopus*

Walker, Entom. Mag., I. 253 (1833) *Enicopus*

Macquart, Hist. Nat. Ins. Dipt., II. 482 (1835) *Nemopoda*

Stæger, Monogr. Sepsid., 35 (1844) *Sepsis*

Zetterstedt, Dipt. Scand., VI. 2304 (1846) *Sepsis*

Schiner, Faun. Austr., Dipt., II. 178 (1864) *Sepsis*

Rondani, Bull. Soc. Ent. Ital., VI. 11 (1874)

varipes Meigen, Syst. Beschr. Zwfl. Ins., VII. 351 (1838) *Nemopoda*

Becker, Zts. Hym. Dipt., II. 230 (1902)

? annulipes India

Brunetti, Rec. Ind. Mus., III. 367 (1909)

bispinosa n. sp., see p 40 Texas

fusca Bigot, see p. 40 Mexico

Megamerina Rondani

annulifera Celebes

Bigot, Ann. Soc. Ent. Fr., 1886, 383 (1886)

dolium C. and N. Europe

Fabricius, Syst. Antl., 315 (1805) *Ocyptera*

Walker, Ins. Brit., II. 218 (1853) *Lissa*

Rondani, Bull. Soc. Ent. Ital., VI. 172 (1874)

loxocerina Fallen, Dipt. Suec. Opomyz., 6 (1820) *Chyliza*

Meigen, Syst. Beschr. Zwfl. Ins., V. 370, pl. lii. f. 1-4 (1826) *Lissa*

Macquart, Hist. Nat. Ins. Dipt., II. 377 (1835) *Lissa*

Schiner, Faun. Austr. Dipt., II. 190 (1864)

fulvida Bigot, see p. 53 Mexico

rufipes Russia

Gimmerthal, Bull. de Moscou, VII. 116 (1834)

Meroplius Rondani

stercorarius Desvoidy, see p. 34 and figs. 4 and 27 Europe; N. and S. America

Nemopoda Desvoidy

algira Algeria

Macquart, Dipt. Exot., II. (3) 232 (1843)

Lucas, Explor. Scient. de l'Algerie, III. 499 (1849)

aterrima Bigot, see p. 38 California

brunicosa France

Desvoidy, Myodaires, 745 (1830)

coerulifrons Macquart, see p. 38 Pennsylvania

cothurnata W. Africa

Bigot, Ann. Soc. Ent. Fr., 1891, 385 (1891)

cubensis, see p. 39 Cuba

cylindrica Fabricius, see p. 37 and fig. 27 Europe, Africa, America

depilis Sierra Leone

Walker, List Dipt. Brit. Mus., IV. 1001 (1849) *Sepsis*

fulviceps Argentina

Bigot, Ann. Soc. Ent. Fr., 1886, 391 (1886)

fumipennis England

Walker, Entom. Mag. I. 253 (1833)

gagatea France

Desvoidy, Myodaires, 745 (1830)

lateralis S. America

Macquart, Dipt. Exot., II. 390 (1843)

nigrilatera S. Europe

Macquart, Hist. Nat. Ins. Dipt., II. 481 (1835)

Meigen, Syst. Beschr. Zwfl. Ins., VII. 351 (1838)
Rondani, Bull. Soc. Ent. Ital., VI. 178 (1874)

obscuripennis Bigot, see p. 39 California

pallipes India
Bigot, nomen nud.

pectinulata C. Europe
Loew, Europ. Dipt., III. 305 (1873)

retronotata Celebes
Bigot, Ann. Soc. Ent. Fr., (6) VI. 391 (1886)

rufa Locality unknown
Walker, List. Dipt. Brit. Mus., IV. 1000 (1849) *Sepsis*

senegalensis Sierra Leone
Bigot, Ann. Soc. Ent. Fr., (6) VI. 389 (1886)

tarsalis England
Walker, Entom. Mag. I. 252 (1833)

tricolor Sirrea Leone
Walker, List Dipt. Brit. Mus., IV. 1001 (1849) *Sepsis*

umbripennis Holland
Wulp, Tijdschr. f. Ent., XIV. 190 (1871)

varipes (not Meigen) Europe; Egypt
Stæger, Kröjer's Tidskr., I. 34 (1844) *Sepsis*
Zetterstedt, Dipt. Scand., VI. 2303 (1847) *Sepsis*
Walker, Entomologist, 92, 345 (1871)

viridis France
Macquart, Hist. Nat. Ins. Dipt., II. 481 (1835)
Meigen, Syst. Beschr. Zwfl. Ins., VII. 351 (1838)

xanthostoma Argentina
Bigot, Ann. Soc. Ent. Fr., (6) VI. 391 (1886)

Pandora Haliday

albipennis France
Macquart, Hist. Nat. Ins. Dipt., II. 545 (1835) *Anisophysa*

basalis England
Haliday, Entom. Mag., I. 170 (1833)

? **longipes** France
Desvoidy, Myodaires, 747 (1830) *Saltella*

metatarsalis India
Brunetti, Rec. Ind. Mus., III. 369 (1909) *Saltella*

? **nana** France
Desvoidy, Myodaires, 747 (1830) *Saltella*

scutellaris Fallen, see p. 49 and fig. 22 Europe and N. America

setigera India
Brunetti, Rec. Ind. Mus., III. 368, f. 19 (1909) **Saltella**

Sepsis Fallen

adjuncta India
Brunetti, Rec. Ind. Mus., III. f. 14 (1909)

æneipes Formosa
Meijere, Ann. Mus. Hung., XI. 114 (1913)

albicoxa Brazil
Thomson, Eugenies Resa, Dipt. 586 (1868)

albolimbata Formosa
Meijere, Ann. Mus. Hung., XI. 114 (1913)

albopunctata Seychelles
Lamb, Tr. Linn. Soc., XVI. 323 (1914)

apicalis Papua
Meijere, Ann. Mus. Hung., IV. 168 (1906)

armata Brazil
Schiner, Reise Novara, Zool. Dipt., 261 (1868)

armillata, n. sp., see p. 18 and fig. 6 West Indies

astutis Rhodesia
Adams, Kansas Univ. Sci. Bull., III. 174 (1906)

atripes Europe
Desvoidy, Myodaires, 743 (1830) *Micropeza*
Macquart, Hist. Nat. Ins. Dipt., II. 478 (1835)
Meigen, Syst. Beschr. zwfl. Ins., VII. 349 (1838)
Stæger, Monogr. Seps., 29 (1844)
Perris, Ann. Soc. Ent. Fr., 1876, 230 (1876)
Frey, Deut. Ent. Zts., 1908, 584, fig. (1908)

barbata Turkestan; Canary Islands
Becker, Ann. Mus. Zool. St. Petersb., XII. 292 (1907); Mitt. Zool. Mus. Berlin, IV. 145 (1908)

barbipes Germany
Meigen, Syst. Beschr. zwfl. Ins., V. 289 (1826)
Macquart, Hist. Nat. Ins. Dipt., II. 479 (1835)
Becker, Zts. Hym. Dipt., II. 229 (1902)

basifera East Indies
Walker, Proc. Linn. Soc., III. 124 (1859); V. 165 (1861)
Meijere, Ann. Mus. Hung., IV. 170, f. 3, 4 (1906)

beckeri India
Meijere, Ann. Mus. Hung., IV. 185, f. 14 (1906)

bicolor China, India, East Indies
Widemann, Aus. zwfl. Ins., II. 468 (1830)
Brunetti, Rec. Ind. Mus., III. 364 (1909)

acuta Meijere, Ann. Mus. Hung., XI. 114 (1913)
breviappendiculata Meijere, Ann. Mus. Hung., XI. 114 (1913)
javanica Meijere, Bijd. Dierk., XVIII. 107, f. 18 (1904); Ann. Mus. Hung., IV. 184, f. 13 (1906)

biflexuosa Austria
Strobl, Wien. Ent. Ztg., XXII. 225 (1893)

brevicosta India

Brunetti, Rec. Ind. Mus., III. 360 (1909)

brevis India

Brunetti, Rec. Ind. Mus., III. f. 15 (1909)

complicata China

Wiedemann, Auss. zwfl. Ins., II. 408 (1830)

concinna England

Walker, Entom. Mag., I. 249 (1833)

coprophila India, Papua

Meijere, Ann. Mus. Hung., IV. 178, f. 10 (1906)
Brunetti, Rec. Ind. Mus., III. 362 (1909)

cornuta Europe

Meigen, Syst. Beschr. zwfl. Ins., V. 288 (1826)
Macquart, Hist. Nat. Ins. Dipt., II. 479 (1835)
Zetterstedt, Dipt. Scand., VI. 2286 (1847)
Becker, Zts. Hym. Dipt., II. 228 (1902)

costalis (not Johnson) S. America

Wiedemann, Auss. zwfl. Ins., II. 467 (1830)

costata, nom. nov. Somaliland

costalis, Johnson, Proc. Acad. Phila., 1898, 163 (1898)

cynipsea Europe; Africa; Asia

Linnæus, Fauna Suec., 1668 (1761) *Musca*
Scopoli, Entom. carn., 947 (1763) *Musca*
Fabricius, Spec. Ins., II. 451 (1781) *Musca*
Schrank, Enumer. Ins. Austr., 956 (1781) *Musca;* Faun. Boica. III. 2461 (1803) *Musca*
Latreille, Gen. Crust. et Ins., IV. 355 (1805) *Micropeza*
Fallen, Dipt. Suec. Ortalid., 23 (1820)
Meigen, Syst. Beschr. zwfl. Ins., V. 287 (1826)
Walker, Entom. Mag., I. 247 (1833)
Macquart, Hist. Nat. Ins. Dipt., II. 477 (1835)
Westwood, Introd. Mod. Class. of Ins., II. 572 (1840)
Stæger, Monogr. Seps., 27 (1844)
Zetterstedt, Dipt. Scand., VI. 2284 (1847)
Lucas, Explorat. de l'Algerie, III. 498 (1849)
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Laboulbene, Bull. Soc. Ent. Fr., 1896, 111 (1896) habits
Becker, Mitt. Zool. Mus. Berlin, IV. 146 (1908)
Frey, Deut. Ent. Zts., 1908, 583, fig. (1908)
Brunetti, Rec. Ind. Mus., III. 345 (1909)

fulgens Meigen, Syst. Beschr. zwfl. Ins., V. 287 (1826)
Walker, Entom. Mag., I. 248 (1833)

Macquart, Hist. Nat. Ins. Dipt., II. 477 (1835)
Becker, Zts. Hym. Dipt., II. 228 (1902)

fulgida Desvoidy, Myodaires, 742 (1830) *Micropeza*

hilaris Meigen, Syst. Beschr. zwfl. Ins., V. 288 (1826)
Walker, Entom. Mag., I. 248 (1833)
Macquart, Hist. Nat. Ins. Dipt., II. 477 (1835)
Becker, Zts. Hym. Dipt., II. 228 (1902)

vivida Desvoidy, Myodaires, 742 (1830) *Micropeza*

decipiens Papua
Meijere, Ann. Mus. Hung., IV. 177, f. 9 (1906)
delectabilis Rhodesia
Adams, Kansas Univ. Sci. Bull., III. 174 (1906)
dilata India
Brunetti, Rec. Ind. Mus., III. 356 (1909)
discolor Bigot, see p. 16 and fig. 7 West Indies
dissimilis India
Brunetti, Rec. Ind. Mus., III. 355, f. 8 (1909)
duplicata England
Haliday, Ann. Nat. Hist., II. 186 (1838)
Curtis, Brit. Ins., 1297, App. 280 (1839)
ecalcarata Thomson, see p. 16 California
ephippium Eritrea
Bezzi, Bull. Soc. Ent. Ital., XXXIX. 170 (1908)
fasciculata India; Ceylon
Brunetti, Rec. Ind. Mus., III. 365 (1909)
fascipes Macassar
Walker, Proc. Linn. Soc., IV. 163 (1860)
fissa Egypt
Becker, Mitt. Zool. Mus. Berlin, II. 143 (1903)
flava India
Brunetti, Rec. Ind. Mus., III. 351, f. 4, 5 (1909)
flavimana (not Schiner) Europe; Asia; Africa
Meigen, Syst. Beschr. zwfl. Ins., V. 288 (1826)
Walker, Entom. Mag., I. 248 (1833)
Stæger, Monogr. Seps., 27 (1843)
Zetterstedt, Dipt. Scand., VI. 2287 (1847)
Lucas, Explor. scient. de l'Algerie, III. 498 (1849)
Strobl, Wein. Ent. Ztg., XII. 126 (1893)
Becker, Mitt. Zool. Mus. Berlin, IV. 146 (1908)
Frey, Deut. Ent. Zts., 1908, 582, fig. (1908)

ruficornis Meigen, Syst. Beschr. zwfl. Ins. V. 288 (1826)
Walker, Entom. Mag., I. 249 (1833)
Macquart, Hist. Nat. Ins. Dipt., II. 477 (1835)
Becker, Zts. Hym. Dipt., II. 228 (1902)

formosana Formosa

Matsumura, Mem. Soc. Ent. Belgique, XVIII. 139 (1911)

fragilis Egypt; Canary Islands

Becker, Mitt. Zool. Mus. Berlin, II. 145 (1903); IV. 146 (1908)

frontalis Macassar

Walker, Proc. Linn. Soc., IV. 163 (1860)

fulvicoxalis Bigot, see p. 30 California

fulvolateralis India

Brunetti, Rec. Ind. Mus., III. 349 (1909)

furcata n. sp., see p. 19 and fig. 11 West Indies

fuscipes Germany

v. Roser, Württemb. Correspbl., 60 (1840)

Becker, Jahresber. Ver. Naturk. Württemb. VI. 54 (1902)

geniculata Canary Islands

Bigot, Bull. Soc. Zool. Fr., XVI. 278 (1890)

Becker, Mitt. Zool. Mus. Berl., IV. 146 (1908)

hæmorrhoidalis Brazil

Schiner, Reise Novara, Zool. Dipt., 261 (1868)

hamata Java

Meijere, Tijdschr. Ent., LIV. 364 (1911)

himalayensis India

Brunetti, Rec. Ind. Mus., III. 345 (1909)

hirsuta N. S. Wales

Meijere, Ann. Mus. Hung., IV. 186 (1906)

hoplicnema, n. sp., see p. 17 and fig. 12 West Indies

humeralis India

Brunetti, Rec. Ind. Mus., III. 362 (1909)

hirtipes Egypt

Becker, Mitt. Zool. Mus. Berlin, II. 142 (1903)

hyalipennis Egypt

Macquart, Dipt. Exot. Suppl., IV. 296 (1850)

igniventris Mauritius

Thomson, Eugenies Resa, 587 (1868)

immaculata Reunion Island

Macquart, Dipt. Exot., II. 391, pl. 31, f. 13 (1843)

incisa Europe

Strobl, Dipt. Steierm., II. 106 (1894)

Frey, Deut. Ent. Zts., 1908, 582, fig. (1908)

indica India

Wiedemann, Analecta Entom., 57 (1824); Auss. zwfl. Ins., II. 467 (1830)

Brunetti, Rec. Ind. Mus., III. 357, f. 9-13 (1909)

fusciventris Bigot, nom. nud.

inpunctata Canary Islands, Egypt

Macquart, Hist. Nat. d. Iles Canaries, 118 (1839); Dipt. Exot., II. (3) 233 (1843)

Becker, Mitt. Zool. Mus. Berlin, II. 144 (1903); IV. 145 (1908)

rufa Macquart, Dipt. Exot. Suppl., IV. 296 (1850)

Becker, Mitt. Zool. Mus. Berlin, II. (3) 144 (1903); IV. 145 (1908)

Meijere, Ann. Mus. Hung., IV. 179 (1906)

Brunetti, Rec. Ind. Mus., III. 359 (1909)

insularis Williston, see p. 19 and fig. 5 West Indies, Florida

lateralis China

Wiedmann, Auss. zwfl. Ins., II. 468 (1830)

limbata Papua

Meijere, Ann. Mus. Hung., IV. 169, f. 2 (1906)

linearis Philippines

Walker, List Dipt. Brit. Mus., IV. 998 (1849)

lineatipes India

Brunetti, Rec. Ind. Mus., III. 354 (1909)

luteipes, nom. nov., see p. 29 and fig. 9 Europe; N. America

flavimana Schiner (not Meigen), Faun. Austr. Dipt. II. 180 (1864)

maculipes England

Walker, Entom. Mag., I. 248 (1833)

melanota Senegal

Bigot, Ann. Soc. Ent. Fr., (6) VI. 388 (1886)

minima Austria

Strobl, Wien. Ent. Ztg., XII. 225 (1893)

modesta India

Meijere, Ann. Mus. Hung., IV. 172 (1906)

monostigma China

Thomson, Eugenies Resa, 587 (1868)

neocynipsea, n. sp., see p. 28 and fig. 17 N. America

nepalensis India

Brunetti, Rec. Ind. Mus., III. 363 (1909)

nigripes Europe

Meigen, Syst. Beschr. zwfl. Ins., V. 289 (1826)

Walker, Entom. Mag., I. 249 (1833)

Macquart, Hist. Nat. Ins. Dipt., II. 478 (1835)

Stæger, Monogr. Seps., 28 (1844)

Zetterstedt, Dipt. Scand., VI. 2286 (1847)

Rondani, Bull. Soc. Ent. Ital., VI. 174 (1874)

Becker, Zts. Hym. Dipt., II. 229 (1902)

Frey, Deut. Ent. Zts., 1908, 584, fig. (1908)

nitida Desvoidy, Myodaires, 743 (1830) *Micropeza*

nitens China

Weidemann, Analecta Entom., 57 (1824); Auss. zwfl. Ins., II. 467 (1830)

nivelpennis Egypt

Becker, Mitt. Zool. Mus. Berlin, II. 143 (1903)

nodosa Sierra Leone

Walker, List Dipt. Brit Mus., IV. 999 (1849)

orthocnemis Finland

Frey, Deut. Ent. Zts., 1908, 583, fig. (1908)

pectoralis Macquart, see p. 23 and fig. 13 Europe, N. America

petulantis Rhodesia

Adams, Kansas Univ. Sci. Bull. III. 176 (1906)

pilipes Holland

Wulp, Tijdschr. Ent., XIV. 189 (1871)

plebeia Sidney

Meijere, Ann. Mus. Hung., IV. 171 (1906)

pleuralis Coquillett, see p. 15 Texas

plumata New Guinea

Meijere, Dipt. I. Nova Guinea, 363 (1913)

propinqua Rhodesia

Adams, Kansas Univ. Sci. Bull., III. 175 (1906)

pubipes India

Brunetti, Rec. Ind. Mus., III. 365, f. 16-18 (1909)

punctum Europe; N. Africa; Madeira

Fabricius, Entom. Syst., 351 (1794); Musca; Syst. Antl., 22 (1805) *Tephritis*

Latreille, Gen. Crust. Ins., IV. 355 (1805) *Micropeza*

Fallen, Dipt. Suec. Ortalid., 22 (1820)

Meigen, Syst. Beschr. zwfl. Ins., V. 289 (1826)

Walker, Entom. Mag., I. 250 (1833)

Macquart, Hist. Nat. Dipt., II. 478 (1835)

Zetterstedt, Ins. Lapp., 745 (1838); Dipt. Scand., VI. 2288 (1847)

Stæger, Monogr. Seps., 25 (1844)

Lucas, Explor. Scient. de l'Algerie, III. 498 (1849)

Walker, Ins. Brit. Dipt., II. 209 (1853)

Schiner, Faun. Austr. Dipt., II. 179 (1864)

Rondani, Bull. Soc. Ent. Ital., VI. 175 (1874)

Perris, Ann. Soc. Ent. Fr., 1876, 230 (1876)

Strobl, Wien. Ent. Ztg., XII. 126 (1893)

Becker Mitt. Zool. Mus. Berlin, IV. 146 (1908)

Frey, Deut. Ent. Zts., 1908, 581 (1908)

?Brunetti, Rec. Ind. Mus., III. 347 f. 3 (1909)

cynipsea Desvoidy, Myodaires, 741 (1830) *Micropeza*

ornata Meigen, Syst. Beschr. zwfl. Ins., V. 290 (1826)

Walker, Entom. Mag., I. 250 (1833)

Macquart, Hist. Nat. Dipt., II. 478 (1835)

Becker, Zts. Hym. Dipt., II. 229 (1902)

stigma Panzer, Fauna Germ., LX. 21 (1798)

pusio S. America
Schiner, Reise Novara, Zool. Dipt., 262 (1868)

pyrrhosoma, n. sp., see p. 25 and fig. 14 E. United States

revocans Macassar; Philippines
Walker, Proc. Linn. Soc., IV. 163 (1860)
Osten Sacken, Berlin. Ent. Zts., XXVI. 238 (1882)

rufa (not Macquart) Rhodesia
Adams, Kansas Univ. Sci. Bull. 176 (1906)

rufibasis India
Brunetti, Rec. Ind. Mus., III. 348 (1909)
major Brunetti, Rec. Ind. Mus., III. 349 (1909)
obscuripes Brunetti, Rec. Ind. Mus., III. 349 (1909)

rufipectus India
Brunetti, Rec. Ind. Mus., III. 352 (1909)

rufipes Germany
Meigen, Syst. Beschr. zwfl. Ins., VII. 349, female not male (1838)

Sauteri Formosa
Meijere, Ann. Mus. Hung., XI. 114 (1913)

signifera, n. sp., see p. 26 and figs. 10, 19 N.America

similis (not Macquart) India
Brunetti, Rec. Ind. Mus., III. 348 (1909)

spectabilis India; Papua
Meijere, Ann. Mus. Hung., IV. 179, f. 10 (1906)

tenella India
Meijere, Ann. Mus. Hung., IV. 183, f. 12 (1906)
Brunetti, Rec. Ind. Mus., III. 362 (1909)

testacea Macassar
Walker, Proc. Linn. Soc., IV. 163 (1860)

thoracica France
Desvoidy, Myodaires, 742 (1830) *Micropeza*

tincta India
Brunetti, Rec. Ind. Mus., III. 353, f. 6, 7 (1909)

tridens Egypt; Canary Islands
Becker, Mitt. Zool. Mus. Berlin, II. 145 (1903); IV. 146 (1908)

trivittata Ceylon, India
Bigot, Ann. Soc. Ent. Fr., (6) VI. 388 (1886)
Meijere, Ann. Mus. Hung. IV. 173 (1909)

umbrifer S. America
Schiner, Reise Novara, Zool. Dipt., 262 (1868)

uncta Persia
Becker, Ann. Mus. Zool. St. Petersb., XVII. 648 (1913)

vicaria Walker, see p. 25 and fig. 18 N. America

viduata China, India, Philippines

Thomson, Eugenies Resa, Dipt., 586 (1868)

Brunetti, Rec. Ind. Mus., III. 366 (1909)

formicoides Bigot, nom. nud. *Nemopoda*

violacea Meigen, see p. 20 and figs. 2, 3, 8 Europe; N. Africa; N. America

Sepsidimorpha Frey

pilipes Europe

Loew, Europ. Dipt., III. 304 (1873) *Sepsis*

Loewi Handel, Wein. Ent. Ztg., XXI. 265 (1902) *Sepsis*

Frey, Deut. Ent. Zts., 1908, 584 (1908)

secunda, n. sp., see p. 32 and fig. 28 N. America

Themira Desvoidy

albitarsis N. Europe

Zetterstedt, Dipt. Scand., VI. 2297 (1847) *Sepsis*

ciliata Europe

Stæger, Sepsid., Kröjer's Tidskr., I. 1, 30 (1844) *Sepsis*

Zetterstedt, Dipt. Scand., VI. 2292 (1847) *Sepsis*

Schiner, Faun. Austr. Dipt., II. 182 (1864)

Rondani, Bull. Soc. Ent. Ital., VI. 177 (1874) *Halidaya*

consobrina (*?minor* Schiner, not Haliday) Holland

Wulp, Tijdschr. Ent., XIV. 192 (1871)

curvipes Holland

Wulp, Tijdschr. Ent., VII. 137, pl. viii. f. 9-14 (1864); XIV. 192 (1871)

dentimana Holland

Wulp, Tijdschr. Ent., VII. 135, pl. viii. f. 8 (1864)

flavicoxa, n. sp., see p. 46 E. United States

gracilis N. Europe

Zetterstedt, Dipt. Scand., VI. 2300 (1847) *Sepsis*

incisurata, n. sp., see p. 44 and fig. 23 United States

Leachi Europe

Meigen, Syst. Beschr. zwfl. Ins., V. 291 (1826) *Sepsis*

Walker, Entom. Mag., I. 255 (1833)

Macquart, Hist. Nat. Dipt., II. 480 (1835) *Cheligaster*

Bouche, Naturgesch., I. 95, pl. vi., f. 8-11 (1837)

Westwood, Introd. Classif. Ins., II. 572 (1840)

Stæger, Sepsid. Kröjer's Tidskr., I. 31 (1844)

Zetterstedt, Dipt. Scand., VI. 2293 (1847) *Sepsis*

Walker, Ins. Brit. Dipt., II. 212 (1853)

Schiner, Faun. Austr. Dipt., II. 182 (1864)

Brauer, Zwfl. Kais. Mus. Wien, 1883, 84 (1883)

Becker, Zts. Hym. Dipt., II. 230 (1902)

coxarum Zetterstedt, Ins. Lapp., 748, female not male (1838) *Sepsis*

malformans, n. sp., see p. 46 — Canada

melitensis — Italy
Rondani, Bull. Soc. Ent. Ital., VI. 176 (1874) *Meroplius*

minor, Haliday, see p. 47 and fig. 24 — Europe; N. Africa; N. America

nigricornis — Europe
Meigen, Syst. Beschr. zwfl. Ins., V. 291 (1826) *Sepsis*
Walker, Entom. Mag., I. 252 (1833) *Nemopoda*
Macquart, Hist. Nat. Dipt., II. 481 (1835) *Nemopoda*
Becker, Zts. Hym. Dipt., II. 229 (1902)

?cylindrica Fallen, Dipt. Suec. Ortalid., 22 (1830) *Sepsis*

Falleni Stæger, Sepsid. Kröjer's Tidskr., I. 32 (1844) *Sepsis*
Zetterstedt, Dipt. Scand., VI. 2296 (1847) *Sepsis*
Schiner, Faun. Austr. Dipt., II. 183 (1864)
Rondani, Bull. Soc. Ent. Ital., VI. 177 (1874) *Meroplius*

Leachi Zetterstedt, Ins. Lapp. 748 (1838)

phantasma — France
Desvoidy, Myodaires, 746 (1830)
Macquart, Hist. Nat. Dipt., II. 480 (1835) *Cheligaster*

pilosa — W. Europe
Desvoidy, Myodaires, 746 (1830)
Walker, Entom. Mag., I. 254 (1833)

superba Haliday, Entom. Mag., I. 170 (1833)

pusilla — N. Europe
Zetterstedt, Dipt. Scand., VI. 2295 (1847) *Sepsis*
putris, var. b., Zetterstedt, Ins. Lapp. 748 (1838) *Sepsis*

putris Linnæus, see p. 43 and fig. 25 — Europe; N. America

Schembrii — Italy
Rondani, Bull. Soc. Ent. Ital., VI. 176 (1874) *Meroplius*

spinosa — England
Verrall, Entom. Month. Mag., XXII. 233 (1885)

Family PIOPHILIDÆ

Mycetaulus Loew

analis — Germany
Meigen, Syst. Beschr. zwfl. Ins., V. 244 ♀ (1826) *Cordylura*

varius Meigen, Syst. Beschr. zwfl. Ins., V. 245 ♂ (1826) *Cordylura;* VII. 339 (1838) *Chyliza*
Becker, Zts. Hym. Dipt., II. 215 (1902)

bipunctatus Fallen, see p. 74 — Europe; N. America

longipennis Loew, see p. 75 — N. America

Piophila Fallen

affinis Meigen, see p. 61 Europe; N. America

analis Germany

v. Roser, Württemb. Correspbl., 61 (1840)

Becker, Jahresber. Ver. Naturk. Württemb., XIV. 56 (1902)

apii (Meijere refers to *Psila*, Ber. Ned. Ent. Ver., III. 141 (1911))

arctica N. Europe

Holmgren, Entom. Tidskr., IV. 177 (1883)

aterrima Nova Zembla

Becker, Mem. Acad. Sci. St. Petersb., 1897, 402 (1897)

atrifrons, n. sp., see p. 66 W. United States

cærulescens Scandanavia

Zetterstedt, Dipt. Scand., VI. 2517 (1847)

casei Linnæus, see p. 68 and fig. 1 Cosmopolitan

concolor Thomson, see p. 72 California

confinis Germany

Meigen, Syst. Beschr. zwfl. Ins., VI. 383 (1830)

Schiner, Faun. Austr. Dipt., II. 186 (1864)

contecta Macassar

Walker, Proc. Linn. Soc., IV. 167 (1860)

dichæta Formosa

Hendel, Suppl. Ent. Berlin, II. 85 (1913)

? disjuncta New Guinea

Walker, Proc. Linn. Soc., VIII. 127 (1864)

flaviceps Sweden

Zetterstedt, Dipt. Scand., VI. 2518 (1847)

flavipes Sweden

Zetterstedt, Dipt. Scand., VI. 2518 (1847)

flavitarsis Europe

Meigen, Syst. Beschr. zwfl. Ins., VI. 383 (1830)

Macquart, Hist. Nat. Dipt., II. 542 (1835)

Schiner, Faun. Austr. Dipt., II. 186 (1864)

Becker, Zts. Hym. Dipt., II. 248 (1902)

fulviceps Nova Zembla

Holmgren, Entom. Tidskr., IV. 177 (1833)

picea Becker, Mem. Acad. Imp. Sci. St. Petersb., 1897, 404 (1897)

lævigata Germany

Meigen, Syst. Beschr. zwfl. Ins., VII. 361 (1838)

Schiner, Faun. Austr. Dipt., II. 186 (1864)

latipes Germany

Meigen, Syst. Beschr. zwfl. Ins., VII. 360 (1838)

Schiner, Faun. Austr. Dipt., II. 186 (1864)

Rondani, Bull. Soc. Ent. Ital., VI. 250 (1874)

liturata, n. sp., see p. 60 W. United States

lonchæoides Sweden
Zetterstedt, Ins. Lapp., 773 (1838); Dipt. Scand., VI. 2519 (1847)

luteata Ireland
Haliday, Entom. Mag., I. 169 (1833)
Walker, Ins. Brit. Dipt., II. 222 (1853)

metallica Greece
Brulle, Eped. Sci. Moree, 324 (1832)

nigerrima Lundbeck, see p. 71 Greenland

nigra Greece
Brulle, Exped. Sci. Moree, 325 (1832)

nigriceps Meigen, see p. 66 Europe; N. America

nigricornis Europe
Meigen, Syst. Beschr. zwfl. Ins., V. 397 (1826)
Macquart, Hist. Nat. Dipt., II. 542 (1835)
Zetterstedt, Dipt. Scand., VI. 2518 (1847)
Becker, Zts. Hym. Dipt., II. 248 (1902)

nigricoxa, n. sp., see p. 64 W. United States

nigrimana Europe; Canary Islands
Meigen, Syst. Beschr. zwfl. Ins., V. 396, pl. liv. f. 5 (1826)
Macquart, Hist. Nat. Dipt., II. 542 (1835); Hist. Nat. Iles Canaries, 118 (1839)
Zetterstedt, Dipt. Scand., VI. 2513 (1847)
Becker, Zts. Hym. Dipt., II. 248 (1902)
nigrifemur Strobl, Mitt. Bosn. Herceg., IX. 560 (1904)

nitens, nom. nov., see p. 70 Wisconsin

nitida (not Wulp) Greece
Brulle, Exped. Sci. Moree, 325 (1832)

nitidissima, n. sp., see p. 66. W. United States

occipitalis, n. sp., see p. 65 Illinois

oriens, n. sp., see p. 63 United States

pilosa Stæger, see p. 71 Greenland

pusilla Meigen, see p. 61 Europe; N. America

ruficornis India; Sumatra
Wulp, Dipt. Sumatra. Exp., 49 (1881)
Brunetti, Rec. Ind. Mus., III. 367 (1909)
flavifacies Brunetti, Rec. Ind. Mus., III. 367 (1909)

ruficoxa France
Macquart, Hist. Nat. Dipt., II. 543 (1835)
Meigen, Syst. Beschr. zwfl. Ins., VII. 361 (1838)

senescens, nom. nov., see p. 72 N. America

setosa, n. sp., see p. 64 Alaska

Smithii New Zealand
Hutton, Trans. N. Zeal. Inst., XXXIII. 89 (1901)

spiculata Europe
Pandelle, Etudes Entom., III. 427 (1902)

varipes Europe

Meigen, Syst. Beschr. zwfl. Ins., VI. 384 (1830)
Macquart, Hist. Nat. Dipt., II. 543 (1835)
v. Roser, Württemb. Correspbl., 1840, 60 (1840) *Psila*
Zetterstedt, Dipt. Scand., VI. 2512 (1847)
Schiner, Faun. Austr. Dipt., II. 186 (1864)

vicina Germany

Meigen, Syst. Beschr. zwfl. Ins., VII. 362 (1838)
Schiner, Faun. Austr. Dipt., II. 186 (1864)

viridis France

Macquart, Hist. Nat. Dipt., II. 543 (1835)
Meigen, Syst. Beschr. zwfl. Ins., VII. 361 (1838)

xanthopoda, n. sp., see p. 63 (as *flavipes*) W. United States

Prochyliza Walker

xanthostoma Walker see p. 56 N. America

Pseudoceps Becker

signata N. Europe

Fallen, Dipt. Suec. Opomyz., 9 (1820) **Scatophaga**
Meigen, Syst. Beschr. zwfl. Ins., V. 360 (1826) **Psila**
Zetterstedt, Ann. Soc. Ent. Fr., IV. 186 (1835) **Scatophaga**; Dipt. Scand., VI. 2409 ♂ not ♀ (1847) **Scatophaga**
Becker, Zts. Hym. Dipt., II. 243 (1902)

latipalpis Zetterstedt, Dipt. Scand., VII. 2411, ♀ (1847) *Scatophaga*

punctipennis Zetterstedt, Dip. Scand., VII. 2516 (1847) *Piophila*

Rhynchæa Zetterstedt

lonchæoides Sweden

Zetterstedt, Dipt. Scand., VI. 2524 (1847)
Schiner, Faun. Austr. Dipt., II. 189 (1864)

Scotimyza Macquart

fuscipennis France

Macquart, Hist. Nat. Dipt., II. 541 (1835)

Toxopoda Macquart

nitida Egypt

Macquart, Dipt. Exot. Suppl., IV. 299 (1850)

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(Italics indicate synonyms; capitals indicate genera)

ERRATUM

p. 63. Read *Piophila xanthostoma,* n. sp. instead of *P. flavipes,* n. sp.

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF CHEMISTRY

Wheat and Flour Investigations—V.

By

GEO. A. OLSON

BULLETIN NO. 144
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PART TWO

PART THREE

WHEAT AND FLOUR INVESTIGATIONS—V.

By Geo. A. Olson, Chemist.

INTRODUCTION

The Chemistry Division of the Washington Experiment Station has been actively engaged in an extensive study of the composition and quality of Washington wheats since 1905. Several bulletins on the progress of these investigations have appeared in print. Bulletins Nos. 84, 91 and 100 are concerned with composition and milling qualities of the principal varieties of wheat grown in several climatically different wheat producing sections of the state. Bulletin No. 102 contains the results of a study which led to the discovery of a reliable method for selecting desirable seed for use in breeding work, having increase of nitrogen as its purpose. Bulletin No. 111 is a study of the effect of environmental influences upon the chemical composition of wheat and also contains a brief report upon the experiments in breeding for increased nitrogen content.

In the course of the investigation, studies of the composition of hybrid wheats, the chemical changes taking place in the progressive development of the wheat kernel, the influences of soil composition and contour of land on the composition of wheat, and certain allied problems, have been carried on. This bulletin is an additional report of a part of our cereal investigations and contains the results of more or less closely related studies. Part One reports results (a) of a comparative study of the composition and baking qualities of flour obtained from various sections of the United States, (b) of the influence of the water-soluble, alcohol-soluble or gliadin-free and salt-free extracts and electrolytes on the baking qualities of flour. Part Two is a progress report on the influence of various components contained in flour on baking quality; and Part Three reports the results of a study of the milling value of water soaked wheat.

HISTORICAL

The oldest idea is that the gluten in flour holds the gas in panary fermentation. Humphries (Humphries and Simpson) (17) states that the gas-retaining capacities of flours indicate their relative strength. "The gas produced in the earliest stages of panary fermentation is lost so far as effect of aeration of the dough is concerned." Barth (4) states, "that the quantity of gluten and the amount of water which it will absorb is a means to the measurement of the quality of flour." Hamann (13) states in his conclusions that, "the baking quality of flour depends upon the gluten content * * * and particularly upon the composition of the gluten and the individual constituents of the gluten." He further states, "there appears to be a relation between the capabilities for absorbing water and baking, however, the capability for absorption of water alone is no expression of its possibilities for baking." Bremer (5) states that, "the experimental data make it appear doubtful whether the soluble nitrogenous constituents affect baking quality." The experiments conducted by different German investigators (Heine and Merker, Edler, Heinrich) reviewed by Hamann (13) show that, "they were unable to express any relationship between the gluten content of flours and their baking qualities." Heine and Millon (13), however, concluded that in general flours having high gluten content also have good baking qualities, but as none of the flours used were poor in baking qualities, they were unable to show that the baking quality was proportional to the gluten content, since flours relatively poor in gluten content showed fairly good baking qualities. Snyder (48, 49) has stated that "good baking flours should contain at least 11% of protein (nitrogen multiplied by factor 5.7) and the protein should have a content of 55 to 65% gliadin." Shutt (45) is of the opinion that "good quality flour should contain 1.93% to 2.10% of nitrogen (11 to 12% protein, N x 5.7)." In a later report (47) Shutt states, "that an increased protein content does not indicate any marked increase in quality or strength." "Immature, abnormal or

backward seasons may result in flours of high percentages of protein." Neither has he been able to support the view that strong flours should contain 55 to 65% of gliadin in their proteins, nor that the strength is relative to the amount of gliadin present, "tho there is some evidence in its favor."

Quality appears to be associated with what European investigators call strength. Accordingly, one would be led to believe that the quality of a flour is largely measured by the quantity and quality of the gluten. Other things being equal, a flour containing large quantities of gluten would possess strength, but owing to the unyielding character of the gluten would be unable to expand in baking so as to produce a volume equal to a flour containing considerably less gluten and less tenacious in character. Jago (20) defines strength, "as the measure of the capacity of a flour for producing a bold, large-volumed, well-risen loaf," while the Home Grown Wheat Committee of the National Association of British and Irish Millers (6) defines a strong flour as one "capable of yielding large, well-piled loaves." This latter definition has been analyzed by Wood (64) and interpreted by him as referring to two different things, i. e., size and shape of loaf. A flour in order to possess excellent baking qualities should be capable of forming well-shaped loaves of large volume and the crumb should be of good texture. The shape of the loaf is attributed to the physical characters of the gluten in the flour, while the size of a loaf is believed to be due to the nature and quantity of the food material upon which yeast can grow and multiply in the flour. Reference will be made to Wood's work again in connection with a resume of work done by other investigators, as well as of some investigations conducted here which touch more or less upon the views presented.

One of the important properties that flour possesses and yet one of the most difficult to clearly define, is that of "strength." A flour that yields a relatively large weight of bread as a result of high water absorption, giving a loaf of large volume, bold and well-piled, is said to be one that possesses strength. According to Jago (20) strength is a physical and not a chemical property which at present can only be definitely determined by making baking tests. The ability of a flour to absorb water is recognized by Humphries

and Biffin (18) as a distinct property. Professor Wood (64, 65) has investigated the size and shape of loaf or strength as defined by Humphries and Biffin. In this connection Wood demonstrated from his investigations that the size of loaf depended upon the amount of sugar contained in the flour, together with that formed by diastatic action during the raising of the dough. The total nitrogen and water soluble constituents in the flour, when compared with the bakers' results from the baking of flours, showed that the flour giving the largest loaf also contained the largest amount of nitrogen and ash-free extract, from which results Wood finally stated that "the size of a loaf which a flour could make is directly connected with the rate at which it gave off gas in the later stages of dough fermentation, at the time it was ready for the oven." In this work the physical property of size in a loaf was in accord with certain chemical data, but there were also exceptions noted.

Wood has also noted that strength is associated with a high ratio of protein to salts; and weakness with a low ratio.

Wood believes that the shape of a loaf is due to the soluble salts present in flour and not to any peculiar property of gliadin, since he reports identical results for gliadin obtained from both weak and strong flour, regardless of source. At the suggestion of Hardy, Wood studied the changes which took place when gluten was immersed in solutions of varying concentrations. Wood found that the quality of the gluten was modified by immersion in alkalies, in acids and in salts, and therefore, suggests "that the factor of strength on which shape of loaf depends is the relation between the concentrations of acid and soluble salts in the flour."

Snyder (2, 50, 51) carried on a series of investigations with reference to the influence of increasing and decreasing the gluten content of flour on size of loaf. In a series of experiments Snyder added 10 to 20 per cent of corn flour or starch to flour in order to reduce the gluten content of the whole. In another series he increased the gluten content of the flour by adding gluten. In still another series he removed the gliadin by extraction with alcohol. The results for baking tests with flours treated as above de-

scribed may be summarized as follows: the addition of starch did not alter the size or appearance of the loaf. Likewise, the addition of gluten did not alter the size or appearance of the loaf. On the other hand, the removal of gliadin resulted in producing a loaf about one-half normal size and decidedly inferior in other respects to the loaf produced from normal flour. From these investigations Snyder concluded that "it is evident that the bread-making properties of flour depend upon the nature of the gluten, as any alteration of the character of the gluten, or the proportion of its constituents in the flour has a strong influence upon the character of the bread produced."

In Snyder's first experiment, the ratio of total nitrogen to soluble salts would have been constant, if the corn flour or starch had been nitrogen-free and ash-free, but the nitrogen-free and ash-free extract would have been decreased. In the experiment in which gluten was added, the ratio of total nitrogen to soluble salts has been increased and the total nitrogen-free and ash-free extract has been decreased. In the case of the third experiment, in which gliadin was removed, the writer is not prepared to state definitely whether or not the ratio of nitrogen to soluble salts has increased or decreased. The writer (34, 36) has pointed out that alcohol of a strength such as was used by Snyder dissolves other proteins besides gliadin, also some of the ash constituents, sugar, fat, etc., and in such a case it appears as tho the ratio of total nitrogen to soluble ash would increase rather than decrease and the nitrogen-free and ash-free extract decrease.

Shutt (46) in a study of flour made from different commercial grades of wheat has shown that the size or volume does not accord with, but "is rather the reverse of" Wood's theory, since he found the highest nitrogen-free and ash-free extracts and lowest volumes in the lower commercial grades of wheat. Omitting some irregularities, Shutt's studies with reference to the ratio of total nitrogen to soluble ash agree with Wood's work on shape of loaf.

From the facts presented, it will be noted that the ratio of total nitrogen to soluble salts, and also the total amounts of nitrogen-free and ash-free extract in a given weight of flour were modified in Snyder's experiments without affect-

ing the size or appearance of the loaves when compared with the loaves baked from the normal untreated flour, while Shutt's results for commercial grades of flour are the reverse of those obtained by Wood with flours furnished the latter investigator by Humphries.

In a comparative study of these reported results, the writer has not been able to determine definitely whether Wood's results were based upon baker's results, on straight bakes or bakes made after several handlings of the dough. It is assumed that his results were based on straight bakes. Among other things with reference to strength of flour, Humphries (17) makes this statement: "A two-pound loaf measuring 3000 cc. is better aerated than one measuring 2200 cc., and is therefore more likely to digest easily." These volumes are equal to 1500 cc. and 1100 cc., respectively, for one-pound loaves. It is assumed that the scores and classification of flours used by Wood in his study on the chemistry of wheaten flour were based on volumes identical with those mentioned by Humphries in his Winnipeg address (17). At any rate it is known that some of the experimental work was based on volumes ranging from 2294 cc. down to 2012 cc. per two-pound loaf (Jour. Agr. Sci., Vol. 1, p. 53), which are comparatively the same as the results obtained by Wood on a smaller scale for straight bakes. The writer is of the opinion that Shutt's results for volume of the loaf were based on more than one handling of the dough (41, 42, 43). The latter method of handling the dough before the bake should give much larger volumes than it would be possible to secure in straight bakes and any defect noted in this process might be entirely overcome when the dough is handled several times before the bake.

Electrolytes such as alkalies and acids modify the properties of gluten to the extent of producing dispersion. The degree of gluten dispersion will depend upon the concentration of the acid or alkali and upon the quantity of salt present (65). Electrolytes such as salts of any kind tend to lessen the power of dispersion in the presence of alkali or acid. According to Wood, Wood and Hardy (66), and Hardy (14), salts modify the physical properties of gluten, changing it into an elastic, coherent mass.

In our investigations (31) we have demonstrated that

flour can be so treated as to alter the quantity of gluten recoverable. This is accomplished by the addition of acid, alkali or salts to flour. The addition of acid or alkali to flour decreases the quantity of gluten recoverable, while some salts increase the quantity over that possible to be obtained from flour not so treated. The addition of acid or alkali, in other words, disperses the gluten at a rate dependent upon the concentration. In such a process it must not be overlooked that these added materials and especially the acids also increase the ratio of soluble salts to total nitrogen.

Allway and Hartzell (1) have made a most thoro study of the relation existing between the volume of loaf and the evolution of gas. From the results obtained by the last named investigators it has been noted that the gas evolved bears no direct relation to the size of the loaf. This is exactly what one would expect, since it is difficult to see how the gas which escapes and which can be measured has anything to do with the volume of the loaf.

Other references on the subject of baking qualities of flours might be given, but owing to the fact that most of the material does not bear directly upon the subject matter presented in this bulletin, such references have not been included.

PART ONE

(a) Relation of Water-Soluble Solids, Alcohol-Soluble Nitrogen, Alcohol-Soluble-Coagulable Nitrogen, Acidity, and Gluten Content to Baking Qualities of Flours Received from Various States.

In order to develop wheat which is suited to our climatic conditions and which at the same time has excellent baking qualities, it is evident that it will be necessary to determine the factors which determine quality. It has been assumed upon insufficient evidence that certain definite ratios between the proteins contained in flour are necessary to make bread of excellent quality. The exceptions to the rules laid down have been numerous enough to make it clear that the factors which determine baking quality are not yet wholly known, and it is for this reason that it has been impossible to correlate analytical data with the results obtained in baking tests. Consequently, analytical determinations of the composition of wheat and flour have been of no positive value in determining the fitness of such wheat and flour for baking purposes, while, on the other hand, practical baking tests where properly conducted have revealed the quality of various flours, regardless of their composition. It has also been found that the baking quality of the flour derived from one wheat is often superior to that made from others of similar composition.

In Bulletin No. 84 of this Station (56) results of baking tests on flour made from the 1905 wheat crop are reported. Baking tests were also made upon the straight flours obtained from the 1907 and 1908 Bluestem wheat crops of low nitrogen and ash, high nitrogen and ash, high nitrogen and low ash, medium nitrogen and high ash, medium nitrogen and low ash. Baking tests were also made with Fife, Turkey Red, Club, Fortyfold and Red Russian varieties. The results obtained for the last two mentioned years have not been published for several reasons. First, the differences observed in the baking qualities did not show constant or consistent volume differences in relation to the nitrogen

and gluten content. Second, the volumes were the results of straight bakes. Third, the activity of the yeast was difficult to control. Fourth, the means for measuring the volumes were unsatisfactory. Fifth, the conditions necessary for making a good loaf of bread had not been determined, nor had correlation between the results of chemical analyses and those of baking tests been established.

The percentages of wet and dry gluten, nitrogen, starch, ash, water, and the nitrogen content of the dry gluten were determined for the flours used in the baking tests (33). The total water insoluble and soluble phosphoric acid were also determined in the hope that the results might give some indication of the causes of variation in baking quality. From the unsatisfactory results that we obtained, it was evident to the writer that no progress could be made, either in working out methods for comparison or in the improvement of the wheat for baking purposes, until a more satisfactory knowledge of the causes of variations could be secured. The results obtained did not follow any set of rules laid down. The exceptions were frequent and as a result the writer decided to carry on a study of the factors which might or might not determine the baking quality by methods entirely different from those generally employed. The results of these investigations will be considered in Part Two of this bulletin.

In planning the investigation reported in Part One, it occurred to the writer that if what are commonly known in the trade as weak and strong flours could be collected from various regions of the United States, it might be possible from a systematic study to determine the chemical significance of these expressions, with a view to properly classifying Washington flours and determining whether it is possible to improve our poorer grades of flour or wheats from which they are made.

In response to a request addressed to the Directors of the various Agricultural Experiment Stations in the United States, samples of flour were received from the states of New York, Michigan, Minnesota, North and South Dakota, Iowa, Kansas, Utah, Montana, Colorado and Texas. The samples of flour were undoubtedly representative of the quality of the flours produced in various widely separated

localities in the United States. The study pursued was with respect to the chemical composition and to the breadmaking qualities and from the results obtained it was hoped to ascertain if it were possible to definitely correlate baking quality of flour with chemical composition.

All of the flours received were stored for adjustment before being subjected to the various tests mentioned in this bulletin. The different flours have been tabulated in the order of their volume-producing capacity, that giving the largest volume obtained is the first one, that giving the lowest volume obtained is the last one in the series under study. It has been deemed advisable by the writer not to disclose the makers or the brand names of the various flours which were furnished us by millers in the different states in compliance with our request for flours considered both weak and strong for baking purposes.

Among the different flours under study were some made on small experimental mills, among which may be mentioned No. 6754, the next to the highest in point of production of volume. This was a patent flour furnished by Frank A. Spragg, cerealist of the Michigan Agricultural Experiment Station, which had been milled on three pairs of rolls; coarse corrugated rolls were used for the first three breaks, finer corrugated ones were used to finish the bran and shorts, while smooth rolls were used to complete the pulverizing of the flour. The Michigan Agricultural College and the Department of Home Economics of the Ohio State University obtained volume capacities for this flour from the 1910 crop of wheat averaging 2163 cc. (52) when 340 grams of flour were used, while our results with the same amount of flour gave a volume capacity of 2210 cc. for the flour made from the wheat of the 1911 crop.

Composition of Flour.

Just what determinations will reveal the strength and baking qualities of flour is at present not settled. A chemical analysis, as generally made, shows the composition of the flour or the grain from which it is made and is of value for comparative purposes. It shows the range of variation in composition possible as a result of variations in cli-

matic conditions, methods of seeding, fertility, soil composition, etc.

Flour is composed of water, fat, crude fiber (cellulose), ash, starch, protein and other nitrogenous substances, and some sugar. In the following analyses the sugar, starch, crude fiber and other non-nitrogenous materials and fat are classified as "carbohydrates and fat" and are computed from the sum of the other results subtracted from 100.

All nitrogen determinations were made by the Kjeldahl method. The moisture determinations were made by drying the flour to constant weight in the vacuum oven at 95 degrees C. and under a pressure of 110 millimeters of mercury. The ash determinations were made by incinerating the flour over direct flame in the usual manner.

In addition to the above determinations, a quantitative study of the alcohol-soluble and alcohol-soluble-coagulable portions of the nitrogenous components of flour was made. These investigations were considered necessary owing to the fact that the methods that have been used for some time past point to the fact that the differentiation of proteins in flour have not been sharp. It has been observed by the writer (34) that the alcohol-soluble portion of the flour includes other nitrogenous material besides gliadin, while in the case of salt-soluble nitrogen materials in flour (36), a part of the gliadin nitrogen of the flour is included. The method used in estimating the alcohol-soluble-coagulable nitrogen as devised by the writer has been discussed in articles by the writer entitled "The Quantitative Estimation of Gliadin in Flour and Gluten" (34) and "The Quantitative Estimation of the Salt-Soluble Proteins in Wheat Flour" (36). In these articles references to the work of Osborne and Voorhees (39, 40), Teller (53, 54), Chamberlain (8, 9), Shutt (47), Hummel (16), Hoagland (15), Shaw and Gaumitz (44), Greaves (12) and Leach (23), have been given and their work discussed. For the convenience of the reader, the method used by the writer in estimating the alcohol-soluble-coagulable nitrogen in the flour is given below.

Digest four grams of flour with 200 cc. of 50 per cent alcohol by volume. Shake the contents at five-minute intervals for the first two hours, then let stand over night and finally filter clear. Determine the per cent of nitrogen in

25 cc. aliquots of the alcoholic solution. Evaporate slowly 50 cc. aliquots of the alcoholic solution to 5 cc. volume, add 50 cc. distilled water, heat nearly to boiling, and continue process until the volume has been reduced approximately to 10 cc. Repeat adding 50 cc. of water and boiling down to 35 cc. volume. Allow contents of beakers to cool to room temperature, then filter. If necessary, repeat filtration until filtrate becomes clear. Estimate the per cent of nitrogen contained in the filtrate and deduct this result from the per cent of alcohol-soluble nitrogen to get the per cent of gliadin nitrogen in the flour.

Although no determinations were attempted in this series of flours for the estimation of the salt-soluble components, such as edestin and leucosin, methods of separation have been accomplished and published in one of the scientific journals (36).

Baking Tests.

Fleischmann's yeast was used in all the experiments herein reported. The compressed yeast was weighed out, worked up and thoroly mixed with distilled water so that each 20 cc. would contain 2.94 grams of yeast.

Both sugar and salt were dissolved in the same distilled water, each 20 cc. of distilled water containing 2.94 grams of sugar and 1.47 grams of salt.

Flour in 100-gram lots was used for the baking tests. For 100 grams of flour 20 cc. of yeast mixture, 20 cc. sugar-salt solution and sufficient distilled water to make the proper consistency was used in all cases. It will be seen that the only variable was the amount of water required to make a dough of proper consistency.

The ingredients, salt, sugar, yeast and water, were mixed with a part of the 100 grams of flour and allowed to stand five minutes, after which the balance of the flour was worked up and rolled until the dough had a uniform consistency to the touch thruout the mass. The dough was then coated with a thin film of olive oil, placed in pans for straight bake and allowed to rise at a constant temperature of 29 degrees C. to a proper height.* It was then taken

*The proper height was determined from experience. All experimental work conducted to scientifically measure the proper height to raise the dough failed.

out of the rising oven, weighed and baked at a temperature of 220 degrees C. for twenty minutes. After an interval of an hour the bread was weighed and the volume determined, from which data the apparent specific gravity was computed. The loaves were then placed in a cool, moist oven until the next morning, when they were cut open in order that the crumb of the loaves might be examined and photographed.

In addition to the straight bakes, loaves of bread were made from dough which had been kneaded one or more times after the first rise. In case of the dough receiving only one kneading, this was placed in a dish and put in constant temperature oven to rise to proper height, then kneaded down and placed in the baking tin and allowed to rise to proper height for the baking. The process of handling the dough and bread, with these exceptions, was the same as in the straight bake. The process of two kneadings differed from that of one kneading in that the dough was allowed to rise in the dish a second time before it was placed in the tin for the final rise and bake.

The results obtained for volume for the different flours under study were not necessarily the largest that might have been obtained. A slight variation in the amount of yeast, sugar and salt might have altered the volume considerably, but inasmuch as it was desirable to compare the results, it was necessary that a uniform quantity of these ingredients should be used thruout the experiment. The variable activity of the yeast used in the different lots may have resulted in some variations in the results, but these variations could not be detected by study of the results with the flour used for check.

That our methods for baking cannot be very different from those adopted at other experiment stations where baking tests are regularly made can be seen from the results obtained by flour specialists who made baking tests in conjunction with the writer in a comparative study on a sample of Washington hybrid wheat flour, known as Turkey Bluestem.

TABLE NO. I.

Baking Tests with Turkey Bluestem Wheat Flour by Different Experts.

Expert	Flour used grams	Volume of Loaf, cc.	Water Absorption per cent
Gevi M. Thomas, Fargo, N. D.	340	2100	58.8
R. Harcourt, Guelph, Canada	340	2190	65.3
C. H. Bailey, St. Paul, Minn.	340	2115	59.1
J. A. LeClerc, Washington, D. C.	340	2026	69.0
Geo. A. Olson, Pullman, Wash.	340*	2169*	65.5

*Calculated from results for 100 grams of flour.

Altho these workers do not agree in regard to the amount of water required to make the best dough, the volumes obtained do not appear to be influenced to any great extent by the variations in the amount of water used. The volumes obtained were more nearly uniform when the absorption was approximately 65½% for this flour.

In a more extended investigation on the influence of water and kneading on this flour, the writer (see Popular Bulletin No. 47) obtained considerable differences in volume and texture. In these tests, 2.94 grams of yeast, 1.47 grams of salt, 2.94 grams of sugar and 100 grams of flour were used in each case. The temperature of the fermentation oven and baking oven and the length of time for the baking were uniformly controlled in each case. The results are herewith given.

TABLE NO. II.

Influence of Water and Kneading on Size and Texture of Loaf.

STRAIGHT BAKE—

Amount of Water	Wt. of Loaf*	Volume*	Total Time to Make
52.5 per cent	1.08 lb.	74.25 cu. in.	240 min.
60.0 per cent	1.12 lb.	93.33 cu. in	193 min.
65.5 per cent	1.15 lb.	103.29 cu. in.	150 min.
73.0 per cent	1.20 lb.	102.87 cu. in.	165 min.

ONE KNEADING BAKE—

Amount of Water	Wt. of Loaf*	Volume*	Total Time to Make
52.5 per cent	1.09 lb.	92.92 cu. in.	300 min.
60.0 per cent	1.15 lb.	111.58 cu. in.	260 min.
65.5 per cent	1.16 lb.	122.77 cu. in.	250 min.
73.0 per cent	1.20 lb.	107.85 cu. in.	215 min.

TWO KNEADING BAKE—

Amount of Water	Wt. of Loaf*	Volume*	Total Time to Make
52.5 per cent	1.06 lb.	99.14 cu. in.	370 min.
60.0 per cent	1.10 lb.	108.68 cu. in.	325 min.
65.5 per cent	1.20 lb.	132.32 cu. in.	310 min.
73.0 per cent	1.20 lb.	121.54 cu. in.	240 min.

THREE KNEADING BAKE—

Amount of Water	Wt. of Loaf*	Volume*	Total Time to Make
65.5 per cent	1.10 lb.	124.44 cu. in.	380 min.
73.0 per cent	1.18 lb.	119.05 cu. in.	290 min.

*The figures for the weights and volumes were computed from measurements obtained by the metric system.

Baking Tins. The first type of baking tins used in the laboratory was the Koelner (55) form. As it was occasionally necessary to make baking tests on smaller samples than the 340 grams required for the Koelner process, these tins were discarded for smaller ones requiring 100 grams of flour, which gave as satisfactory results. The writer tested out various forms of tins, both cylindrical and cubical, and finally adopted the cubical form. These tins were made in different sizes of 100 cc., 200 cc., 300 cc., 500 cc., 700 cc., and 900 cc. volumes. After considerable experimentation, the 700 cc. tin was adopted for general use, for the reason that the doughs baked in this size tin seldom bulged out and over its sides. In instances of the kind just referred to, the baking tests had to be repeated in the larger sized

tins in order to obtain reliable results, since the flours were to be tested and classified according to their bread volume capacity. By confining the dough in sufficiently large sized tins it was found that duplication of volumes could be made within 10 cc. of each other. On the other hand, when the dough sprung up and over the sides of the tin, the results for volume of loaf were found to be unreliable.

Measuring the Volume of Loaf. In measuring the volume of the loaf various methods were tried. In the first experiments, the loaves were placed in a vessel of known capacity and wheat was poured in to fill the vessel, but inasmuch as the errors in measurements by this method were sometimes as much as 10 per cent it was discarded. Volume measurement was also attempted by paraffining the loaf and measuring the water displaced (22), but the results obtained could not be depended upon, since the loaves would absorb water in varying amounts in spite of the fact that they were thoroly covered with paraffin. The most accurate determinations of the volume of the loaf were made by placing the loaves in vessels of known capacity, which were then filled with lead shot, since it is possible to either measure or weigh the shot and compute the volume with occuracy. It was found, however, that the volumes obtained by the lead-shot method were much smaller than those obtained by other methods of measurement and consequently the results obtained could not be compared with those reported at other experiment stations. Another objection to the use of lead shot is the discoloration which results from the coating of lead on the outside of the loaf. We also constructed rubber sacks for the measurement of the volume with unsatisfactory results.

Clover seed and German millet seed were also tried and after considerable experimenting it was found that the measurements of volume with clean millet seed were easily duplicated, and this method was consequently adopted for all the volume measurements on the flours reported in the first part of the bulletin.*

Apparent Specific Gravity. Large well-piled loaves are preferable to small compact ones. The former may contain

*In Part Two some of the results for volume are based on displacement with lead shot.

larger quantities of water than the latter and yet the excess water is not detectable except by actual moisture determination. The compactness of the small loaf makes it soggy, even though it contains less moisture. The larger loaves being more porous are believed to be more digestible than the more compact ones. These physical differences are believed to be due partially to the physical quality of the gluten in retaining carbon dioxide gas in the process of fermentation and also partially to the content of water-soluble substances, such as sugar, amides, etc., which can be used as food by the yeast. The extremes in volume, therefore, are largely due to the physical condition of the dough during the process of fermentation and to the nature and kind of food for yeast present in the flours.

The texture or porosity of bread is an important factor in determining the quality of a flour for bread-making purposes and it is possible to measure this factor in a relative way by determining the apparent specific gravity of the loaf after the bake. The apparent specific gravity is computed from the volume obtained by millet seed displacement and the weight of the loaf one hour after the bake. In order to make this computation of comparative value the loaves of bread were baked in all cases at the same oven temperature and for the same length of time. In our experiments the loaves were baked twenty minutes at a temperature of 220 degrees C., which was found to be ample time to bake 100 grams of flour. It is evident that loaves of equal volume but of different weights will have different specific gravities as a result of the varying amounts of water retained in such loaves during the bake.

Computing the Number of Pound Loaves per Barrel of Flour. The standard formula generally adopted in the United States and Canada calls for 340 grams of flour or 12 ounces to make a one-pound loaf of bread (1 pound = 453.5 grams). Theoretically a barrel of 196 pounds of flour should make at least 261 1/3 one-pound loaves, provided the weight of yeast, sugar and salt used and water retained is not greater than four ounces in the loaf. Any amount greater than the above figure means that the total amount of yeast, sugar and salt used and of water retained in the loaf is greater than four ounces. Consequently, the increase

in weight of each loaf over 16 ounces determines the increased number of loaves over 261 that can be obtained from a barrel of flour. The weight of loaf in grams multiplied by 261, divided by 453.5 (number of grams in a pound) gives the number of loaves of bread to the barrel of flour. This operation can be simplified by using a factor which is obtained by dividing 261 by 453.5 or 0.577. The weight of loaf in grams multiplied by 0.577 equals the possible number of loaves of bread in a barrel according to the standard formula given above. Where 100 grams of flour are used instead of 340 grams the factor would be 3.4 times 0.577 or 1.96. This last figure is the one used by the writer to determine the possible number of loaves of bread in a barrel of flour of 196 pounds when 100 grams of flour are used for the bake.

In Table III, there has been included columns showing number of one-pound loaves which can be made from one barrel of each of the flours, employing the methods here given.

The results for the weights and volumes of loaves made from straight bakes, the dough handled two and three times, for the various flours under study (Table III), also the results obtained from determinations of total nitrogen, ash, acidity (Table IV), composition, different forms of protein (Table V), of the flours arranged in the order of the volumes of the loaves baked from dough handled three times are recorded in the following tables:

Nitrogen, Dry Gluten, and Total Ash Contained in the Different Flours Included.

Number and State	Straight Bake						One Handling of Dough in Addition to Mix						Two Handlings of Dough in Addition to Mix								
	Weight of Dough Grams	Weight of Loaf Grams	Volume of Loaf cc.	Apparent Specific Gravity	Pound Loaves To Barrel	Volume Pound Loaf cc.	Weight of Dough Grams	Weight of Loaf Grams	Volume of Loaf cc.	Apparent Specific Gravity	Pound Loaves to Barrel	Volume Pound Loaf cc.	Weight of Dough Grams	Weight of Loaf Grams	Volume of Loaf cc.	Apparent Specific Gravity	Pound Loaves to Barrel	Volume Pound Loaf cc.	Total Nitrogen Per Cent	Dry Gluten Per Cent	Total Ash Per Cent
6784 Tex.	165.1	146.8	528	0.278	291.6	1795	.....	.....	...	.....	.....	....	162.7	148.6	656	0.227	291.2	2230	1.62	10.87	0.51
6754 Mich.	169.1	153.4	458	0.335	300.8	1557	164.3	150.0	518	0.290	294.0	1761	161.2	143.2	650	0.220	280.4	2210	2.21	13.31	0.44
6772 N. D.	165.9	151.5	572	0.265	297.0	1944	163.9	149.1	585	0.255	292.0	1989	165.4	152.1	648	0.234	298.0	2203	2.33	13.66	0.41
6786 Kan.	169.4	148.8	514	0.290	291.6	1747	176.4	154.0	538	0.288	301.0	1815	164.2	150.8	648	0.233	296.0	2203	2.09	12.31	0.44
6760 S. D.	173.2	156.1	508	0.307	306.2	1727	176.4	160.9	554	0.291	315.0	1883	166.9	155.7	638	0.244	305.4	2169	1.99	12.00	0.52
6751 Wash.	167.4	148.3	478	0.310	290.6	1625	161.9	148.1	582	0.255	290.0	1978	166.6	153.6	638	0.241	301.2	2169	1.86	11.50	0.39
6761 S. D.	170.3	152.8	522	0.293	299.6	1774	.....	.....	...	.....	.....	....	166.1	150.0	628	0.239	294.0	2135	1.93	12.71	0.56
6762 S. D.	170.5	155.0	432	0.359	304.0	1468	170.0	152.2	508	0.300	298.3	1727	170.3	157.0	624	0.252	308.0	2121	2.17	12.56	0.55
6764 Minn.	172.5	146.8	488	0.301	287.6	1659	165.8	142.7	474	0.300	279.7	1611	166.6	153.2	618	0.248	300.4	2101	2.64	15.73	0.72
6774 N. D.	171.6	154.9	548	0.283	303.8	1863	.....	.....	...	.....	.....	....	162.4	152.2	618	0.246	298.0	2101	2.67	16.13	0.51
6765 Minn.	168.2	145.0	522	0.278	284.0	1774	165.6	154.3	540	0.294	302.0	1836	162.1	146.0	614	0.237	286.0	2088	1.86	.....	0.47
6757 Minn.	169.7	147.1	462	0.318	288.2	1570	170.9	149.2	548	0.272	292.0	1863	170.7	155.6	612	0.254	305.2	2080	2.01	11.80	0.44
6780 Ia.	169.1	143.2	452	0.317	280.4	1536	165.0	143.5	488	0.298	283.3	1659	159.2	151.0	610	0.248	296.0	2074	1.91	10.80	0.48
6752 Wash.	173.9	157.2	545	0.289	308.4	1853	163.5	151.0	564	0.268	296.0	1918	165.9	146.7	608	0.241	287.0	2067	....	.....	....
6753 Wash.	173.4	150.0	486	0.309	294.0	1652	161.6	147.6	470	0.308	289.0	1598	174.1	153.1	608	0.252	300.2	2067	2.32	17.18	0.53
6763 Minn.	168.2	149.1	542	0.275	292.2	1842	164.1	140.0	528	0.265	274.4	1795	162.3	151.3	608	0.249	296.6	2067	2.12	11.70	0.45
6770 Colo.	168.4	152.5	498	0.306	299.0	1693	163.6	145.5	528	0.275	285.0	1795	161.0	149.0	608	0.245	292.0	2067	2.11	.....	0.57
6779 Mont.	.....	.....	...	.....	.....	....	177.4	144.4	458	0.315	283.0	1557	167.9	152.1	604	0.252	298.2	2053	2.00	.....	....
6793 Wash.	.....	.....	...	.....	.....	....	.....	.....	...	.....	.....	....	163.6	143.5	600	0.239	281.3	2040	1.93	13.06	0.35
6796 Minn.	168.7	149.5	528	0.283	293.0	1795	.....	.....	...	.....	.....	....	160.9	147.5	600	0.246	289.0	2040	2.22	12.75	0.50
6773 N. D.	169.6	150.0	522	0.287	294.0	1774	167.1	150.6	553	0.272	295.0	1880	163.7	144.3	596	0.242	283.0	2026	2.40	13.98	0.47
6787 Kan.	165.9	142.4	448	0.318	278.8	1523	163.6	146.2	484	0.300	287.0	1645	156.4	141.6	588	0.241	277.0	1999	1.79	11.15	0.51
6781 Ia.	163.9	145.0	448	0.324	284.0	1523	167.2	146.2	488	0.300	286.6	1659	161.5	147.1	588	0.250	288.2	1999	1.84	10.45	0.45
6769 Colo.	169.8	151.3	508	0.298	296.6	1727	162.9	142.5	504	0.282	279.0	1713	164.2	147.9	588	0.252	289.8	1999	1.79	10.50	0.47
6782 Wash.	169.3	146.6	518	0.283	287.2	1761	.....	.....	...	.....	.....	....	168.9	141.2	582	0.243	276.4	1978	1.61	.....	0.40
6788 Kan.	160.1	140.3	458	0.306	274.6	1557	170.4	150.0	502	0.300	294.0	1706	164.1	149.0	578	0.258	292.0	1965	1.69	9.75	0.32
6766 Colo.	169.2	151.3	504	0.300	296.6	1713	.....	.....	...	.....	.....	....	162.4	145.6	578	0.252	285.2	1965	1.78	9.45	0.39
6767 Colo.	170.0	150.0	488	0.307	294.0	1659	159.1	143.6	462	0.311	291.5	1570	164.2	149.0	576	0.259	292.0	1958	1.63	9.87	0.59

TABLE NO. III.—(Continued)

Number and State	Straight Bake: Weight of Dough Grams	Straight Bake: Weight of Loaf Grams	Straight Bake: Volume of Loaf cc.	Straight Bake: Apparent Specific Gravity	Straight Bake: Pound Loaves To Barrel	Straight Bake: Volume Pound Loaf cc.	One Handling of Dough in Addition to Mix: Weight of Dough Grams	One Handling: Weight of Loaf Grams	One Handling: Volume of Loaf cc.	One Handling: Apparent Specific Gravity	One Handling: Pound Loaves to Barrel	One Handling: Volume Loaf cc. Pound	Two Handlings of Dough in Addition to Mix: Weight of Dough Grams	Two Handlings: Weight of Loaf Grams	Two Handlings: Volume of Loaf cc.	Two Handlings: Apparent Specific Gravity	Two Handlings: Pound Loaves to Barrel	Two Handlings: Volume Pound Loaf cc.	Total Nitrogen Per Cent	Dry Gluten Per Cent	Total Ash Per Cent
6802 Wash.	166.9	147.2	468	0.315	278.4	1591	161.8	145.0	508	0.285	284.0	1727	163.0	143.4	568	0.253	283.0	1931	1.33	8.25	0.58
6790 Wash.	165.1	146.3	518	0.283	286.6	1761	163.2	146.2	418	0.349	286.6	1421	158.4	142.4	568	0.251	304.8	1931	1.90	11.15	0.43
6792 Utah	166.2	145.2	498	0.292	284.4	1693	167.0	141.8	454	0.312	278.0	1543	159.2	142.0	558	0.255	278.0	1897	1.73	10.77	0.43
6759 Minn.	170.7	149.0	436	0.342	292.0	1482	163.2	147.7	412	0.358	289.5	1400	162.6	150.2	552	0.272	294.4	1876	2.72	.....	1.50
6756 Mich.	165.9	147.2	498	0.296	288.4	1693	168.6	151.7	468	0.324	297.0	1591	165.9	147.2	548	0.269	288.4	1863	1.69	9.30	0.57
6789 Utah.	166.2	147.6	478	0.309	289.2	1625	167.7	147.9	458	0.323	290.0	1557	172.6	153.5	548	0.280	301.0	1863	1.73	11.38	0.38
6804 Wash.	.....	.....	...	.....	.....	....	162.1	140.8	480	0.293	276.0	1632	161.0	133.7	548	0.244	262.0	1865	1.97	12.94	0.48
6755 Mich.	165.6	148.7	428	0.347	291.4	1455	158.7	146.4	440	0.333	286.9	1496	159.7	147.4	542	0.272	288.8	1842	1.92	10.00	0.50
6785 Tex.	169.0	151.2	428	0.353	296.0	1455	162.1	143.7	470	0.300	281.7	1598	159.9	147.7	540	0.274	289.4	1836	2.03	12.34	0.95
6768 Colo.	170.7	150.0	508	0.295	294.0	1727	.....	.....	...	.....	.....	....	165.3	151.8	540	0.281	297.6	1839	1.78	11.30	0.33
6800 Wash	.....	.....	...	.....	.....	....	160.5	.....	450	.....	.....	1530	160.5	136.6	534	0.256	267.7	1816	1.79	12.41	0.36
6783 Wash.	165.4	143.0	464	0.308	280.0	1577	.....	143.3	457	0.315	281.0	1553	164.4	145.9	518	0.282	285.8	1761	1.49	.....	....
6776 Mont.	168.3	150.5	448	0.336	295.2	1523	169.5	142.0	488	0.291	278.0	1659	164.0	150.0	518	0.290	294.0	1761	1.68	9.30	0.49
6758 Minn.	171.1	149.6	422	0.355	293.2	1434	164.2	145.9	498	0.298	286.0	1693	165.4	152.1	508	0.300	298.2	1727	2.39	14.10	....
6775 N. Y.	166.1	143.6	450	0.319	281.2	1530	165.4	144.5	460	0.314	283.2	1564	164.8	147.2	508	0.290	288.4	1727	1.47	7.30	0.55
6777 Colo.	149.4	149.5	450	0.331	293.0	1536	169.3	153.1	476	0.322	300.0	1618	164.4	149.3	508	0.294	292.6	1727	1.52	10.18	0.43
6771 Colo.	167.2	150.0	502	0.299	294.0	1706	163.8	141.1	458	0.308	276.6	1557	162.3	145.8	500	0.292	285.6	1700	1.82	8.07	0.46
6791 Utah.	166.9	141.0	494	0.286	276.0	1679	165.7	140.5	450	0.312	275.4	1530	162.6	143.0	492	0.302	290.6	1672	1.85	10.83	0.45
6794 Wash.	.....	.....	...	.....	.....	....	.....	.....	...	.....	.....	....	161.8	141.7	470	0.302	277.7	1598	1.95	12.50	0.52
6778 Colo.	164.3	142.5	452	0.311	279.0	1557	166.4	138.8	458	0.303	272.0	1557	164.1	144.5	468	0.309	283.0	1591	1.46	7.90	0.40
5795 Wash.	.....	.....	...	.....	.....	....	.....	.....	...	.....	.....	....	162.5	131.0	462	0.283	256.8	1571	1.90	12.37	0.41
6797 Wash.	.....	.....	...	.....	.....	....	159.0	.....	474	.....	.....	1612	159.0	128.8	424	0.304	252.4	1442	1.85	11.57	0.37
6798 Wash.	.....	.....	...	.....	.....	....	.....	.....	...	.....	.....	....	154.6	131.4	420	0.313	257.5	1428	1.63	10.26	0.30
6799 Wash.	.....	.....	...	.....	.....	....	157.9	135.3	470	0.288	265.2	1598	164.2	135.0	420	0.321	264.6	1428	2.35	16.82	0.58
Average	167.8	143.2	465	0.314	286.0	1581	162.9	145.2	480	0.303	284.6	1632	161.3	144.4	563	0.256	282.2	1914	1.92	11.62	0.48
Maximum	173.9	157.2	572	0.359	308.4	1944	177.4	160.9	585	0.349	315.0	1989	174.1	157.0	656	0.321	308.0	2230	2.72	17.18	1.50
Minimum	149.4	140.3	422	0.265	274.6	1434	158.7	135.3	412	0.255	265.2	1400	154.6	131.0	420	0.220	252.4	1428	1.33	7.30	0.30

TABLE NO. IV.—Composition and Percentages of Various Nitrogenous Components

Number	Moisture Per Cent	Protein (Nx5.7) Per Cent	Carbohyd. and Fat Per Cent	Total Ash Per Cent	Alcohol Sol. Nitrogen Per Cent	Alcohol Insol. Nitrogen Per Cent	Alcohol Coag. Nitrogen Per Cent	Alcohol Non-Coag. Nitrogen Per Cent	Water Sol. Nitrogen Per Cent
6784	8.69	9.23	81.57	0.51	0.91	0.71	0.66	0.25	0.35
6754	8.88	12.59	78.09	0.44	1.13	1.08	0.86	0.27	0.24
6772	8.09	13.27	78.23	0.41	1.40	0.93	0.99	0.41	0.42
6786	8.85	11.91	78.80	0.44	0.99	1.10	0.79	0.20	0.25
6760	8.47	11.35	79.66	0.52	1.27	0.72	0.87	0.40	0.40
6751	8.95	10.60	80.96	0.39	0.98	0.88	0.69	0.31	0.29
6761	7.85	11.00	80.59	0.56	1.25	0.68	0.81	0.44	0.44
6762	7.81	12.47	79.17	0.55	1.33	0.84	0.94	0.39	0.44
6764	8.53	15.04	75.71	0.72	1.56	1.08	1.10	0.46	0.40
6774	8.97	15.24	75.28	0.51	1.40	1.27	1.21	0.29	0.43
6765	8.39	10.29	80.85	0.47	1.00	0.86	0.80	0.20	0.32
6757	8.75	11.45	79.36	0.44	1.15	0.86	0.73	0.42	0.45
6780	9.06	10.89	79.57	0.48	1.10	0.81	0.73	0.37	0.38
6753	8.18	13.22	78.07	0.53	1.44	0.88	1.02	0.42	0.44
6763	9.47	12.08	78.00	0.45	1.29	0.83	0.91	0.38	0.45
6770	8.75	12.03	78.65	0.57	1.21	0.90	0.81	0.40	0.25
6779	9.75	11.40	.....	.....	1.15	0.85	0.67	0.48	.....
6793	9.59	11.00	78.90	0.35	1.13	0.80	0.82	0.31	0.42
6796	11.26	12.66	75.59	0.50	1.31	0.91	0.96	0.35	0.35
6773	8.83	13.68	77.02	0.47	1.53	0.87	1.08	0.45	0.55
6787	8.95	10.20	80.34	0.51	1.08	0.71	0.66	0.42	0.38
6781	8.84	10.49	80.22	0.45	1.04	0.80	0.77	0.27	0.27
6769	8.79	10.20	80.54	0.47	1.24	0.55	0.82	0.42	0.38
6782	9.87	9.17	80.56	0.40	0.87	0.74	0.56	0.31	0.32
6788	9.25	9.63	80.80	0.32	0.95	0.74	0.65	0.30	0.34
6766	9.25	9.47	80.89	0.39	1.04	0.55	0.78	0.26	0.39
6767	8.25	9.29	81.88	0.59	1.08	0.55	0.78	0.30	0.38
6802	8.60	7.58	83.24	0.58	0.61	0.72	0.46	0.15	.....
6790	8.88	10.83	79.86	0.43	1.15	0.75	0.80	0.35	0.44
6792	8.66	9.86	81.05	0.43	[illegible]	0.66	0.63	0.44	0.47
6759	8.62	15.50	74.38	1.50	1.43	1.29	1.02	0.41	.....
6756	8.83	9.63	80.97	0.57	1.01	0.68	0.68	0.33	0.43
6789	8.99	9.75	80.88	0.38	1.05	0.68	0.70	0.35	0.41
6804	9.61	11.10	78.81	0.48	1.05	0.92	0.77	0.28	0.23
6755	8.12	10.94	80.44	0.50	1.14	0.78	0.82	0.32	0.35
6785	8.92	11.57	78.13	0.95	1.08	0.95	0.65	0.43	0.31
6768	8.39	10.15	81.13	0.33	1.23	0.55	0.78	0.45	0.51
6800	9.83	10.20	79.61	0.36	1.06	0.73	0.78	0.28	0.32
6783	9.87	8.49	.....	.....	0.90	0.59	0.58	0.32	0.34
6776	8.93	9.58	81.01	0.49	1.05	0.63	0.52	0.53	0.46
6758	8.95	13.60	.....	.....	1.37	1.02	0.87	0.50	0.38
6775	8.78	8.38	82.29	0.55	0.87	0.60	0.61	0.26	0.38
6777	8.85	8.66	82.06	0.43	0.94	0.58	0.74	0.20	0.22
6771	9.29	10.40	79.85	0.46	0.89	0.93	0.64	0.25	0.25
6791	8.36	10.54	80.65	0.45	1.13	0.72	0.88	0.25	0.32
6794	9.65	11.12	78.71	0.52	1.22	0.73	0.68	0.54	0.46
6778	8.35	8.33	82.92	0.40	0.87	0.59	0.62	0.25	0.28
6795	9.96	10.83	78.80	0.41	1.09	0.81	0.64	0.45	0.39
6797	9.91	10.54	79.18	0.37	1.07	0.78	0.76	0.31	0.37
6798	8.04	9.29	82.37	0.30	0.95	0.68	0.56	0.39	0.34
6799	10.02	13.39	76.01	0.58	1.42	0.93	0.95	0.47	0.52
Average........	8.60	10.94	79.98	0.48	1.13	0.80	0.68	0.45	0.35
Maximum	11.26	15.50	83.24	1.50	1.56	1.29	1.21	0.54	0.55
Minimum	7.81	7.85	74.38	0.30	0.61	0.55	0.46	0.15	0.22

TABLE NO. V.—Wet and Dry Gluten, Total Protein, Alcohol Soluble and Coagulable, Alcohol Insoluble, Total Solids and Acidity in Water Extract, arranged in order Volume Capacity.

Number	Wet Gluten Per Cent	Dry Gluten Per Cent	Protein (Nx5.7) (Per Cent)	Per Cent of Total Protein: Alcohol Insoluble	Per Cent of Total Protein: Alcohol Coagulable	Per Cent of Total Protein: Other Forms	Total Solids in Water Ext.	n/100 Sod. Hydrate C.C.
6784	26.20	10.87	9.23	43.8	40.7	15.5	7.26	2.00
6754	37.60	13.31	12.59	48.9	38.9	12.2	6.08	2.10
6772	37.50	13.66	13.27	44.2	42.5	13.3	8.02	2.00
6786	33.90	12.31	11.91	52.6	37.8	9.6	8.10	1.80
6760	33.00	12.00	11.35	36.2	43.7	20.1	11.36	2.10
6751	33.60	11.50	10.60	47.3	37.1	15.5	6.00	1.50
6761	33.70	12.71	11.00	35.2	41.8	23.0	7.82	2.10
6762	33.60	12.56	12.47	38.7	43.3	18.0	7.12	2.40
6764	41.85	15.76	15.04	40.9	41.7	17.4	6.52	2.80
6774	43.50	16.13	15.24	47.6	45.4	7.0	7.62	1.80
6765	.....	.....	10.29	46.2	43.0	10.8	15.08	1.50
6757	32.80	11.80	11.45	42.8	36.3	20.9	10.76	2.20
6780	29.05	10.80	10.89	42.4	38.2	19.4	9.46	2.70
6752	.....	.....	.....	.....	.....	.....	.....	.....
6753	52.10	17.18	13.22	38.0	43.9	18.1	7.94	2.25
6763	31.00	11.70	12.08	39.2	42.9	17.9	7.82	2.20
6770	.....	.....	12.03	42.7	38.4	18.9	9.58	2.50
6779	.....	.....	11.40	42.5	33.5	24.0	.....	.....
6793	.....	.....	11.00	41.5	42.5	16.0	6.74	1.30
6796	40.00	12.75	12.66	41.0	43.2	15.8	13.86	3.70
6773	37.60	13.98	13.68	33.3	45.0	18.7	12.06	2.00
6787	30.30	11.15	10.20	40.0	37.3	22.7	11.54	3.20
6781	30.10	10.45	10.49	43.5	41.8	14.7	8.38	3.90
6769	29.00	10.50	10.20	30.7	45.8	23.5	8.16	2.00
6782	.....	.....	9.17	46.0	34.8	19.2	5.32	2.10
6788	25.50	9.75	9.63	43.8	38.5	17.7	10.22	2.00
6766	27.10	9.45	9.47	30.9	47.0	20.1	6.98	1.70
6767	26.60	9.87	9.29	33.7	47.8	18.5	8.96	2.20
6802	21.70	8.25	7.58	54.1	.....	.....	.....	.....
6790	30.50	11.15	10.83	39.5	42.1	18.4	6.82	1.90
6792	33.90	10.77	9.86	32.4	36.4	31.2	7.44	1.70
6759	.....	.....	15.50	47.4	37.5	15.1	.....	.....
6756	24.00	9.30	9.63	40.2	40.2	19.6	6.58	2.70
6789	31.70	11.38	9.75	39.3	40.2	20.5	6.78	2.10
6804	39.80	12.94	11.10	46.7	39.1	14.2	8.38	2.30
6755	27.00	10.00	10.94	40.6	42.7	16.7	8.88	2.70
6785	28.50	12.34	11.57	46.8	32.0	21.2	8.16	3.10
6768	33.10	11.30	10.15	30.9	43.8	25.3	7.66	1.30
6800	36.60	12.41	10.20	40.8	43.6	15.6	6.78	1.65
6783	.....	.....	8.49	39.6	38.9	21.5	6.08	1.00
6776	27.70	9.30	9.58	37.5	31.0	31.5	10.96	2.10
6758	37.00	14.10	13.60	42.7	36.0	21.3	11.12	4.30
6775	20.00	7.30	8.38	40.8	41.5	17.7	7.26	3.00
6777	27.40	10.18	8.66	38.2	42.1	19.7	12.20	1.60

TABLE NO. V.—(Continued)

Number	Wet Gluten Per Cent	Dry Gluten Per Cent	Protein (Nx5.7) (Per Cent)	Per Cent of Total Protein: Alcohol Insoluble	Alcohol Coagulable	Other Forms	Total Solids in Water Ext.	n/100 Sod. Hydrate C.C.
6771	21.00	8.07	10.40	56.6	35.2	8.2	7.64	1.70
6791	32.20	10.83	10.54	38.9	47.6	13.5	6.66	2.10
6794	39.10	12.50	11.12	37.4	34.9	27.7	6.84	1.50
6778	21.50	7.90	8.33	40.4	42.4	17.2	8.30	2.10
6795	38.80	12.37	10.83	42.6	31.6	25.8	6.32	1.60
6797	34.60	11.57	10.54	42.2	41.1	16.7	9.40	3.30
6798	30.00	10.26	9.29	41.7	34.3	25.0	5.84	1.60
6799	52.50	16.82	13.39	39.6	40.4	20.0	10.44	4.60
Average	32.59	11.62	10.94	41.7	35.4	22.9	8.44	2.35
Maximum	52.50	17.18	15.50	56.6	47.6	.....	15.08	4.60
Minimum	20.00	7.30	7.58	30.7	31.0	.....	5.32	1.00

Relation of Loaf Volume to Total Nitrogen.

The loaf of bread of largest volume among the 53 flours tested (Table III) was made from number 6784, a patent made from soft wheat grown in the locality of El Paso, Texas. In nitrogen content this flour stood forty-seventh in the entire series. Number 6754, milled on the Michigan Agricultural Experiment Station three-roll mill, gave the second largest volume and was ninth in nitrogen content. Numbers 6772 and 6786 gave loaves of equal volume, and had practically the same nitrogen as number 6754. Number 6772, a medium patent, was sixth in nitrogen, while number 6786, an 80% patent, was thirteenth in nitrogen. Number 6760, a South Dakota patent milled from a native No. 1 Northern wheat, was fifth in volume and eighteenth in nitrogen. Number 6751, a 100 per cent patent milled from a Washington hybrid (Turkey Red-Bluestem cross), was sixth in volume and twenty-fifth in rank in nitrogen. Number 6796, a well-known and generally advertised patent flour, ranked twentieth in volume capacity and eighth in nitrogen content. Number 6802 ranked twenty-ninth in volume and was the lowest in nitrogen of the series. Number 6765 was thirty-second in volume and the highest in nitrogen. The

flour giving the lowest volume contained 2.35 per cent of nitrogen.

The above mentioned facts tend to show that the quality of flour or its volume-producing capacity bears no relation to the total nitrogen content.

Relation of Volume to Total Alcohol-Soluble and Alcohol-Soluble-Coagulable Nitrogen.

Number 6784 was forty-fourth in total alcohol-soluble nitrogen and thirty-seventh in alcohol-soluble-coagulable nitrogen. Number 6754 was twenty-first in total alcohol-soluble and eleventh in alcohol-soluble-coagulable nitrogen. Numbers 6772 and 6786 were respectively fifth and thirty-ninth in total alcohol-soluble nitrogen and fifth and twenty-first in alcohol-soluble-coagulable nitrogen. Number 6764, a Minnesota clear flour ranking ninth in volume, contained 1.56 per cent of alcohol-soluble nitrogen (the highest amount of any in the series) and was second in the amount of alcohol-soluble-coagulable nitrogen. The smallest quantities of alcohol-soluble and alcohol-soluble-coagulable nitrogen was found in number 6802, which ranked twenty-ninth in volume. The flour that gave the lowest volume was third in total alcohol-soluble nitrogen and sixth in alcohol-soluble-coagulable nitrogen. The per cent of the total nitrogen in the flours tested which was alcohol-soluble varied from 43.4 to 69.3, the average being 58.3. The per cent of the total nitrogen which was alcohol-soluble and coagulable varied from 31.0 to 47.6, the average being 35.4. The alcohol-soluble and alcohol-soluble-coagulable nitrogen like the total nitrogen appear to bear no relation to the volume capacity of flour. The composition of some of the flours from which the best volumes were produced is practically that of some of the flours which produced the poorest volumes.

The data for the water-soluble nitrogen, the glutenin nitrogen expressed in per cent of flour and in per cent of total nitrogen, also the per cent of alcohol-soluble nitrogen not coagulable expressed in per cent of flour and in per cent of total nitrogen are included in Tables No. IV and V. With the exception of the water-soluble nitrogen, which

will be discussed in another part of this bulletin, there is no need of a discussion of these figures other than to state that the relation is just as variable as was found to be the case for the total nitrogen, alcohol-soluble nitrogen and alcohol-soluble-coagulable nitrogen.

Total Ash.

The total ash in this series of flours varied from 0.30% for the flour producing next to the lowest volume to 0.95%, the average being 0.48 per cent of ash.* So far the writer has been unable to determine any relationship between total ash of flour and volume production of the same when baked. In general the ash content found is within the limits of those found for patent flours.

Relation of Gluten Content to Volume-Producing Capacity.

The per cent both of dry gluten and wet gluten in this series of flours varies considerably. The highest percentage of wet gluten found was 52.50 or as dry gluten 16.82. The flour containing this quantity of gluten gave the lowest volume found in the series, 420 cc. per 100 grams of flour. The next highest wet gluten content was 52.10% equal to 17.18% dry gluten. The flour with this last mentioned gluten content produced a volume of 608 cc. per 100 grams of flour. The third highest flour in wet gluten contained 43.50% and 16.13% dry gluten and produced a volume of 618cc. per 100 grams of flour. The flour that produced the largest volume, 656 cc. per 100 grams of flour, contained 26.20% of wet and 10.87% of dry gluten. No. 6775, a New York flour used largely for pastry purposes, had a lower gluten content than any other of the flours in the series, viz., 20.0% of wet and 7.30% of dry gluten. Although these few results indicate that the volume is inversely proportional to the gluten content it does not hold true for all of the samples analyzed, and, therefore, as far as our work has proceeded no definite relation can be drawn.

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*Number 6759 is a marked exception, since it gave 1.50 per cent ash.

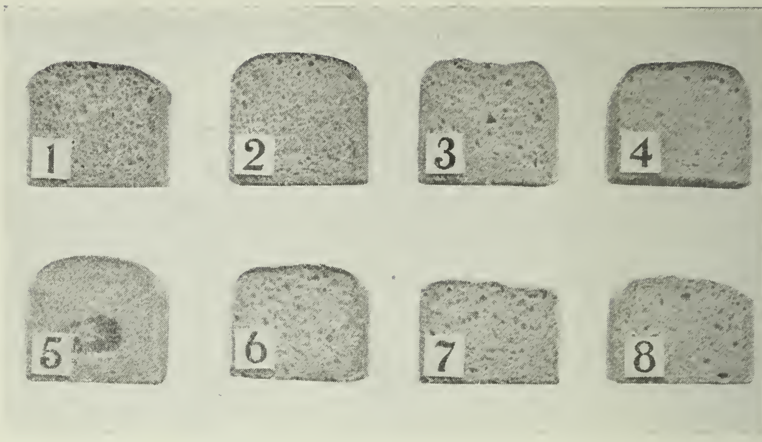


Fig. 1. (Serial No. 7.)

No. 1,—Minnesota Clear; No. 2,—Washington Bakers; No. 3,—Washington Turkey Red-Bluestem Hybrid; No. 4,—Washington Patent; No. 5,—Minnesota Patent; Nos. 6, 7, 8,—Washington Patents.

Fig. 2. (Serial No. 8.)

Reading left to right, top row: Kansas Patent; Minnesota Second Clear; Kansas Patent; Washington Patent. Bottom row: Washington Patent; Little Club; South Dakota Patent; Red Russian Milled on "Special Laboratory" Mill.

Those who desire flours containing high gluten and low ash do not necessarily get flours that will produce the largest volumes in the bake. The baking test will, however, determine whether or not high gluten flours with low ash content are suitable for large volume productions. The same line of reasoning also applies to flours containing much smaller or higher gluten contents.

The Relation Between the Water-Soluble Solids and the Volume-Producing Capacity of Flour.

The quality of flour is sometimes measured by the amount of water-soluble solids that it contains. It is said (24) that a flour should not contain more than 5.0% of such solids to be what is known as a sound flour. If this statement is true then none of the flours examined by the writer can be said to be sound flours. The lowest content of water-soluble solids was found in the case of No. 6782, which contained 5.32%, and the highest was found in the case of No. 6765, which contained 15.08%. The average per cent of water-soluble solids found was 8.44. In three flours obtained from South Dakota, Nos. 6760, 6761 and 6762, the order of rank with respect to soluble solids is also the order of the volume-producing capacity of the flours. In the case of three other flours from another state, Nos. 6772, 6773, and 6774, the highest water-soluble solids is found in the one producing the lowest volume capacity. For the other two, however, the order is that found for the flours from South Dakota.

In general it may be said that the data obtained for the water-soluble solids do not show any relationship to the volume-producing capacities of the flours studied.

Relation of Acidity to Volume-Producing Capacity.

The acidity or the amount of alkali necessary to neutralize a given amount of flour is said to be a measure of soundness of a flour (24). The number of cubic centimeters of N/100 sodium hydroxide required to neutralize the water-soluble extract per gram of flour varied from 1.0 c.c. to 4.6 c.c. The average number of c.c. required

Fig. 3. (Serial No. 9.) External view: Reading left to right, top row—North Dakota; Washington; North Dakota. Bottom row—Minnesota Patent; Washington; North Dakota.

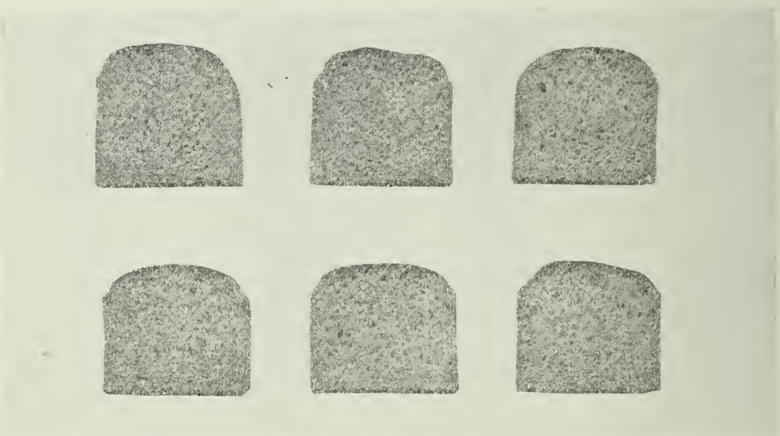


Fig. 4. (Serial No. 9.) Same as Fig. 3. Crumb view.

was 2.35. The data for acidity are somewhat higher than those recorded by other investigators but when the number of hours allowed for the water digestion of the flour, possibilities for bacterial action, etc., are taken into consideration, the results are not as high as one would expect under such conditions. Perhaps a knowledge of the acidity developed in a period equal to the length of time required for the dough to rise for the bake would give a fairer idea as to the value of this kind of a determination. A study of the progressive acid development of flour has not been undertaken. It has been impossible from the data obtained to establish a relationship between the acidity and volume.

Relation of Gluten Content to Water-Retaining Capacity of Flour.

It is generally believed among bakers and millers that the quantity of gluten present in a flour determines its water-holding capacity. The writer has even heard bakers, millers and flour salesmen state that some particular flour will make a larger number of loaves to the barrel than any other because it carries more gluten. The data at hand enable one to determine the correctness of this statement. The possible number of pound loaves of bread that can be obtained from the respective flours under study varied. Number 6760, a 12.71% dry gluten flour, gave 306 loaves per barrel of flour for straight bake, 315 loaves for one kneading, and 302 loaves for two kneadings. Number 6784, flour containing 10.87% dry gluten, yielded 287.6 loaves of bread per barrel for the straight bake and 291.2 loaves for two kneadings. Number 6753, containing 17.18% dry gluten, yielded 294 loaves per barrel of flour for straight bake, 289.2 for one kneading, and 302 loaves for two kneadings. Number 6799 with 16.82% dry gluten netted 267.6 loaves per barrel of flour for two kneadings. Number 6797 with 11.57% dry gluten gave only 252 pound loaves in a two-kneading experiment, while 6775 with only 7.3% dry gluten gave 281.2 pound loaves for the straight bake, 283.2 for the one kneading, and 288.4 pound loaves for the two kneadings. Number 6796, a well-known and generally advertised flour which is represented as being one that will produce

Fig. 5. (Serial No. 10.)

No. 1,—Turkey Red Flour; Nos. 2, 3, 4,—Michigan Flours made on three sets of rolls; Nos. 5, 6, 7, and 8.—Utah Flours.

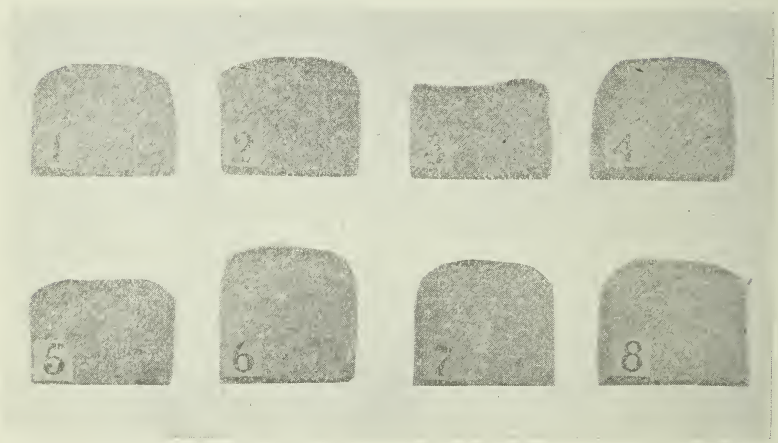


Fig. 6. (Serial No. 14.)

Nos. 1, 2, 3, 4, 7, and 8,—Colorado Flours; Nos. 5, 6,—Texas Flours.

more pound loaves to the barrel than any other, gave 293 pound loaves to the barrel for the straight bake and 289 for two kneadings. The average number of loaves of bread calculated for the barrel was 286 for straight bake, 284.6 for one kneading, 282.2 for two kneadings.

The exceptions noted above are only a few of many striking cases in which flour of high gluten content fell below others of average or low gluten content in bread-producing capacity. None of the results obtained by the writer show a relation between the gluten content and the water-holding capacity of the loaf.

Apparent Specific Gravity of the Baked Loaves.

The data on apparent specific gravities recorded in Table III, is of value to show whether the action of the yeast has been favorable to the production of large volume. As a loaf of a given weight increases in volume the apparent specific gravity decreases. A loaf having an apparent specific gravity of 0.25 or less may be regarded as one which has been properly baked, while one running higher than this figure indicates that the flour has not been handled to the best advantage, or is a flour lacking the qualities which permit the production of large volume.

(b) Investigational Work Pertaining to the Influence of the Removal from Flours of Water-Soluble, Alcohol-Soluble and Salt-Free Extracts, and the Addition to Flour of Electrolytes Upon Baking Qualities.

In the review of literature reference has been made to Wood's theory, with regard to causes determining the volume and shape of loaf. The writer believes Wood's theory was based on results obtained in comparison with bakers' results on straight bakes, while Shutt's work evidently was compared with baking tests made from doughs handled several times. It is, therefore, possible that a disagreement such as was observed by these two workers might have been due to the different methods of handling the dough, and if so it might be well to conduct a series of tests on flour similar to those carried on by Wood and Shutt based entirely on straight bakes rather than upon

the more complicated process. The results for volume would indicate whether or not the disagreements noted were entirely due to the methods of handling the dough.

The writer selected a number of flours used in the wheat and flour investigations at this Station for study as to relation of nitrogen-free and ash-free extracts to volume of loaf. With the exception of the methods used in determining phosphoric acid and potash, the methods adopted were precisely those described by Wood. The organic phosphoric acid was included in the writer's determination for phosphoric acid, and potash was determined gravimetrically as a platinic salt. The results obtained are recorded in the following table. Nitrogen-free and ash-free extracts and relative volumes are also included.

TABLE NO. VI.

Soluble Constituents of Flour and Relative Volume of Loaves made from Flour.

Station No.	Total Solids %	Ash %	Nitrogen %	Potash %	Phosphorus Pentoxide %	Nitrogen free and Ash free Ext. %	Relative Volume
3642	4.928	0.372	0.210	0.138	0.207	3.359	100.0
3608	4.140	0.306	0.179	0.143	0.166	2.814	95.4
3649	4.646	0.402	0.235	0.152	0.334	2.904	92.8
3640	4.656	0.432	0.277	0.180	0.212	2.645	90.0
672 Fr.	5.872	0.604	0.232	0.092	0.337	3.944	82.2
3611	5.606	0.410	0.236	0.168	0.210	3.851	78.9
3602	6.216	0.428	0.249	0.136	0.144	4.369	77.0

The results recorded in Table VI, show that the flours containing the lower percentages of nitrogen-free and ash-free extract gave relatively the larger loaves, while those with the higher nitrogen-free and ash-free extract gave relatively the smaller loaves. The above results agree with those found by Shutt in his study of Canadian wheats. It is of importance to note that the method of handling the dough did not affect the results obtained by the writer.

Determinations for water-soluble ash were not made in the entire series of flours obtained from the various states. However, a sufficient number of water-soluble ash deter-

minations were made to show that from the results obtained (see Table VII) it was impossible to correlate the nitrogen-free and ash-free extract with the volumes obtained for the loaves, either for straight bake or for dough handled several times, before the bake. The writer has, therefore, confirmed his earlier work as reported above. The frequent irregularities for the same and for different volumes indicate that the nitrogen-free and ash-free extract do not show the relation to the volume of the loaf that would be expected according to theory.

TABLE NO. VII.

Soluble Constituents of Flour and Volumes of Loaves Made After two Kneadings and Proving in Pan

Station No.	Total Solids %	Ash %	Nitrogen %	Nitrogen-free Ash-free Extract %	Volume C. C. M.
6784	7.36	0.22	0.35	5.045	656.0
6786	8.10	0.32	0.25	6.355	648.0
6772	8.02	0.30	0.415	5.354	638.0
6765	15.08	0.36	0.32	12.896	614.0
6757	10.76	0.30	0.45	7.895	612.0
6753	7.94	0.36	0.44	5.072	608.0
6770	9.58	0.74	0.25	7.415	608.0
6793	6.74	0.28	0.42	4.066	600.0
6773	12.06	0.22	0.545	8.734	596.0
6787	10.44	0.20	0.38	8.074	588.0
6781	8.38	0.34	0.27	6.501	588.0
6785	8.16	0.24	0.31	6.153	540.0
6800	6.78	0.10	0.32	4.856	534.0
6776	10.96	0.28	0.46	8.058	518.0
6777	12.20	0.34	0.22	10.606	508.0
6797	9.40	0.30	0.37	6.991	424.0
6799	10.44	0.20	0.52	7.276	420.0

Attention has been called to the fact that the size of a loaf is attributed to the amount of nitrogen-free and ash-free extract which a flour contains. This nitrogen-free and ash-free extract being largely in the form of sugar, together with the sugar which forms in the process of dough fermentation, has been considered the essential constituent determining the volume capacity of a flour.

The writer has calculated the ratio of soluble ash, potash, and phosphoric acid to total nitrogen. These figures,

together with those for total nitrogen and relative shape are recorded in Table VIII, and are presented in exactly the form as by Wood with his results, i. e., the ratio of soluble ash constituents to total nitrogen on shape of loaf.

TABLE NO. VIII.

Soluble Ash Constituents of Flour and Relative Shape of Loaf made From Flour.

Station No.	Total Nitrogen %	Ratio of Soluble to Total Nitrogen			Relative Shape
		Ash	Potash	Phosphorus Pentoxide	
3608	1.74	5.69	12.18	10.48	100
3642	1.97	5.30	14.30	9.52	99
3640	2.27	5.25	12.61	10.71	99
3649	2.04	5.07	13.45	6.11	98
3611	1.52	3.76	9.17	7.33	95
3602	1.72	4.02	12.70	11.90	94
672 Fr.	1.62	2.68	17.70	4.81	90

The relative values for shape in this series are in accord with Wood's theory, viz., that the ratio of soluble ash to total nitrogen determines shape. The ratios of total nitrogen to soluble ash with one exception are in the order of their relative shapes. The flour having the best measurement had also the highest ratio and so on down to the lowest.

Referring again to more recent work with flour by the writer it will be noted that flours having similar ratios of total nitrogen to soluble ash do not necessarily produce loaves of similar shape (see Table VII). Some of the flours with the lowest ratios had the best relative shapes. In other words, the irregularities are numerous.

We have found it possible to test the correctness of the theory with reference to shape in another way, viz., by increasing the soluble ash and thereby increasing the ratio of soluble ash to nitrogen. In the first series of trials the acid, alkali, or salt was added directly to the flour in combination with the yeast mixture. The quantity of electrolytes used was exactly 30 c.c. of N/100 or N/10 lactic

or hydrochloric acid, sodium hydroxide, sodium monohydrogen phosphate and sodium chloride, for each 100 grams of flour. A control was run in connection using distilled water and no electrolyte with the yeast mixture. The prepared dough, after having properly fermented, was baked into loaves. The results obtained for weight and volume in this experiment are recorded in Table IX.

TABLE NO. IX.

Influence of Adding Acid, Salt or Alkali on the Baking Quality of Flour.

	N/100 Lactic Acid	N/100 Hydro-chloric Acid	N/100 Sodium Hydrate	N/10 Hydro-chloric Acid	N/10 Sodium Hydrate	N/10 Sodium Chloride	N/10 Sodium Phosphate	Water Used
Wgt. dough .	156.7	159.2	159.2	156.8	156.8	156.6	157.9	156.2
Wgt. loaf ..	139.2	145.6	140.0	130.8	135.8	138.2	143.5	135.5
Vol. loaf ...	330.0	320.0	310.0	302.0	150.0	310.0	320.0	300.0
Ap. Sp. Gr. ..	0.42	0.45	0.45	0.43	0.90	0.45	0.45	0.45

With the addition of electrolytes, the ratio of soluble salts to total nitrogen has increased. Consequently, the shape of the loaf as compared to the control, should improve. The shapes of the loaves as influenced by the electrolytes (N/10, sodium hydroxide excepted) were not very different from the shapes of the loaves obtained in case of the untreated control flour. In some instances the texture of the crumb was slightly more open than in other cases.

The results stated in Table VIII show that lactic acid gave the largest volume loaf, with N/100 hydrochloric acid and N/10 sodium monohydrogen phosphate following next in order. N/100 sodium hydroxide and N/10 sodium chloride gave an increase in size of loaves as compared with that made from the control flour treated with distilled water. N/10 hydrochloric acid gave a loaf equal in size to that obtained for the control. The flour treated with N/10 sodium hydroxide gave a very small loaf. This smaller volume is undoubtedly due to an inhibitory action on the yeast and not to any physical defect in the flour. On the other hand, the addition of salt or acid in the strengths used may have been stimulating to yeast action and in

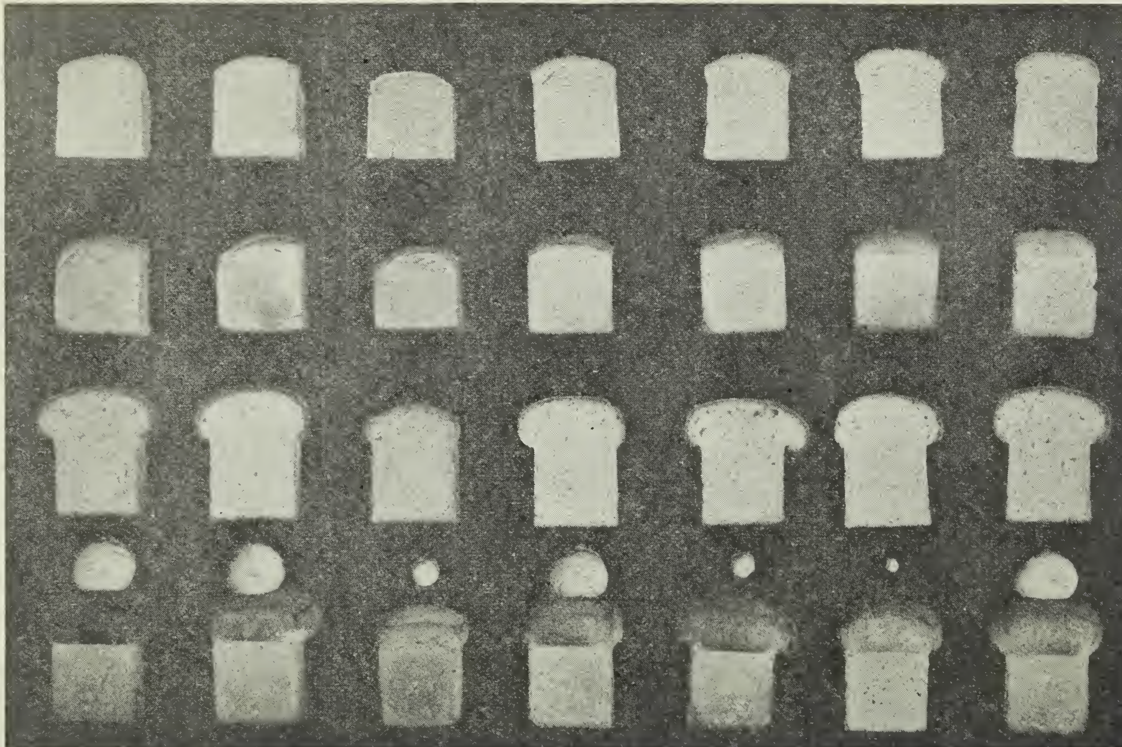


Fig. 7. Two upper rows same as two lower row, difference is in the amount of water used. Reading from left to right—N/100, N/25, N/10 Sodium hydroxide; N/100, N/25, N/10 Lactic acid; control. Gluten masses on top are amounts of gluten recovered from 100 grams of flour.

this way may have improved the volumes regardless of any physical modification of the flour.

In another series the process of increasing the ratio of salt-soluble nitrogen to total nitrogen by the addition of electrolytes was a modification of the one just described, and is as follows: Five 100-gram lots of a high-grade flour were thoroly mixed in a bread mixer with either 60% of water or of N/100, N/25, or N/10 sodium hydroxide, or lactic acid, allowed to stand one hour, after which they were rolled out on glass plates, turned and worked frequently during the process of drying on the dryer. The samples after having dried sufficiently were disintegrated into small particles and dried further until the material was rendered suitable for reduction on the mill. The flour treated with water was run as a control in order to check the flours that had been treated with electrolytes. With the exception of the flour treated with N/10 sodium hydroxide which had a golden yellow color, no perceptible differences were observed.

The flours processed as described were subjected to baking tests. The same quantities of yeast, salt and sugar were used thruout the experiment. As will be seen from the two upper rows in the illustration (Fig. VII) the first test was a failure and for that reason the data were omitted. It was found that a 60% water absorption was insufficient and consequently it was necessary to increase the quantity to 75% of water. The lower rows of bread are the results of baking the treated flour with 75% of water. The masses of gluten upon the top of the loaves are the actual quantities of gluten recovered in each of these flours. The results for weight before and after baking and the volumes are recorded in the table which follows. It might be well to mention in this connection that doughs from the flours which were treated with acid increased in stickiness with the increase in strength of acid and decreased in stickiness with the increase in strength of alkali used.

There are some interesting points to be observed in this experiment, as the data in Table X show the weight of the loaf increases with the increase in concentration of either acid or alkali. The results for N/100 acid or alkali being approximately the same as for the control. On the other

hand, the volumes for the acid-treated flours do not show regular decrease with increase in concentration, while the volumes for alkali flours decrease with the increased strength of alkali. The largest volume obtained was with N/25 lactic acid and the N/100 was slightly better than the control. The lowest volume observed was in case of the flour treated with N/10 sodium hydroxide. The regular decrease in volume for the alkali indicates that this substance has a pronounced effect upon the process of fermentation. In respect to acid there is nothing noted in any way influencing the activity of the yeast.

TABLE NO. X.

Baking Tests with Flour Modified with Either Acid or Alkali.

	Sodium Hydroxide			Lactic Acid			Control
	N/100	N/25	N/10	N/100	N/25	N/10	
Wgt. dough.	173.6	171.8	174.2	171.3	172.3	172.3	171.0
Wgt. loaf ...	146.5	149.3	156.0	147.6	149.0	156.8	147.2
Vol. loaf	365.0	335.0	265.0	315.0	370.0	320.0	360.0
Ap. Sp. Gr. .	0.40	0.448	0.59	0.468	0.40	0.49	0.409

Except for those treated with N/10 sodium hydroxide and N/100 lactic acid the loaves are very similar in shape. The one treated with N/25 lactic acid is slightly more open in texture and also overlapped the pan a little more than any of the others in the series.

In connection with this work we should not overlook the part of the experiment wherein a part of the gluten was dispersed by the addition of acid or alkali. The per cent of wet and dry gluten and the ratio of dry to wet gluten in the flours treated as above described are recorded in the following table:

TABLE NO. XI.

Gluten Determinations of Flour Recorded in Table X.

	Sodium Hydroxide			Lactic Acid			Control	Fermented Dough
	N/100	N/25	N/10	N/100	N/25	N/10		
Per cent wet gluten	24.26	24.80	4.13	22.83	1.90	0.35	24.30	Scattered
Per cent dry gluten	8.38	8.04	1.45	7.41	0.66	0.012	7.81	7.68
Ratio of dry to wet	1:2.89	1:3.08	1:2.85	1:3.08	1:2.88	1:2.91	1:3.11	....

The results recorded in Table XI show the amount of gluten recoverable from flour treated with alkali or acid. This experiment differs from preceding ones by the writer (31) in that the alkali or acid solutions were added to the flour to form a dough which was reconstructed into flour again. The dispersion of gluten does not appear to be affected under this process until the concentration of alkali exceeds 0.06 grams of sodium hydroxide per 100 grams of flour while with a concentration of .24 grams of sodium hydroxide only 4.13% wet gluten was obtained. The lactic acid began to show its effect on gluten dispersion with as small a quantity as 0.0145 grams lactic acid per 100 grams of flour, and with a concentration of 0.54 grams lactic acid per 100 grams of flour there was only a trace of gluten recoverable. The ratios for dry to wet gluten were practically identical with the control in both acid and alkali.

The fact that only a trace of gluten was obtainable in the flours treated with 0.54 grams lactic acid per 100 grams did not alter the baking qualities of that flour in any perceptible degree. Up to the present it has been held by investigators that not only the quantity but also the quality of the gluten is an important factor in determining the quality of a flour for bread-making purposes, and those flours that had the largest quantities of the same quality of gluten were believed to make bread of better quality than was possible with the smaller quantities of gluten.

The writer has extended his researches to determine what substances are of fundamental importance to baking quality in flour. The first of a series of investigations was planned partly to determine the effect of removing the gliadin as Snyder had done and partly to determine the effect of removing a part, if not all, of the soluble salts from flour.

In order to remove gliadin flour was repeatedly extracted with alcohol of 70% strength by volume until no further material could be extracted by this means. In order to remove the soluble salts, the flour was placed in distilled water and subjected to dialysis. In order to remove the greatest possible soluble ash contained in the flour in the shortest possible time, the dialysate was fre-

quently removed and distilled water added in its place. The process was continued in the cold in the presence of chloroform for forty-eight hours, after which the flour was placed on dryer to dry. The dialyzed flour was then dried in a stoneware tray placed upon a radiator and kept cool by an electric fan.

After having dried sufficiently it was crumbled and reduced to the size of clover seed when the process of drying was renewed. The prepared flour was then reduced in the mill (26, 29) and bolted on a 10XX bolting cloth.

Baking Tests of the Gliadin-Free and Salt-Free Flours Compared with an Untreated Control Flour.

The same quantity of yeast and sugar as in the preceding experiment and one-half the quantity of salt was used in each case, but the water content varied with the water-absorbing capacities of the flours. By reason of "putty-like" nature of the gliadin-free flour (as previously noted by Snyder) it required more water than either the dialyzed flour or the control. The data as to time required for the rising of the dough, per cent of water used, the apparent specific gravity of the loaf, the relative volumes in per cent, and the texture of crumb are given in the following table:

TABLE NO. XII.

Baking Tests with Gliadin-Free and Dialyzed Flours Compared with Normal Untreated Flour.

Time for Rising	% Water Required	App. Sp. Gr.	Relative Volume	Texture
Control 3 hours	56	0.44	100	good
Dialyzed 4.5 hours	60	0.57	70	heavy
Gliadin-free 7 hours	85	0.84	50	compact

It will be noted from Table XII that the gliadin-free flour required more water and a much longer time for rising than was necessary in either the control or the dialyzed flour. The relative volume of the loaf and the appar-

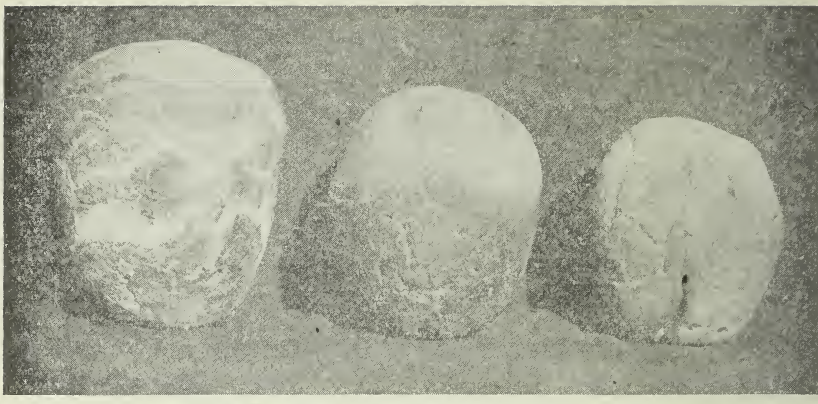


Fig. 8. Reading from left to right: 1—Normal; 2—Dialyzed; 3—Alcohol extracted.

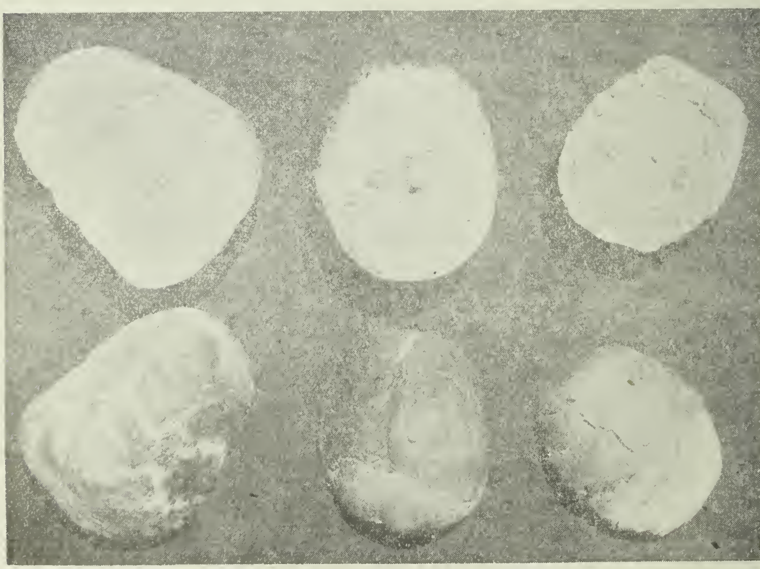


Fig. 9. Loaves cut to show texture of crumb. Normal (largest loaf), dialyzed (in middle) and gliadin free (smallest) flour was used.

ent specific gravity for this flour are also worthy of attention. Altho the gliadin-free flour was taken seven hours after rising had begun, it was no more fit for baking than flour just set with yeast, and from all appearances it is doubtful if it ever would have risen more than it did in this case. This result with gliadin-free flour is similar to that found at both the Minnesota and the New Jersey Experiment Stations.

In regard to the dialyzed flour it will be noted from Table XI that the removal of a part of the ash constituents has affected the size and texture of the loaf somewhat as in the case of the gliadin-free flour. The time required for the dough to rise was also longer than that for the control. The fact that the dialyzed flour yielded only 70% of the volume of the control does not necessarily prove that the decreased size is entirely due to the removal of salts. A decreased ash content, however, has resulted in an inferior baking flour. Perhaps with the addition of soluble salts it might have been possible to again convert the flour into a good one. The fact that some salts are beneficial to yeast growth while others are not must also be taken into consideration.

The two accompanying illustrations, Figs. 8 and 9, herein given, will illustrate the differences observed in the shape, size, and texture of the loaf. The loaf made from the control flour was well-shaped and the crumb had a fairly even texture.

It has been observed by the writer that alcohol extracts of flour contain, in addition to gliadin, edestin, leucosin, amides and other extractive substances such as salts, sugar, etc. Some, if not all, of the substances extracted may be essential to the required physical properties of dough, or beneficial to yeast action, or both. We are conducting investigational work with a view of ascertaining the importance of each of the above mentioned components of flour and also to ascertain whether gliadin is of any importance in modifying the physical properties of the dough or in any way influencing the action of the yeast.

The work contained in this part of this bulletin does not show any of the relationships between the chemical components and the baking qualities of flour which have been

discussed by different experts. The experiment on the dispersion of gluten is a strong argument against the theory that the quantity or the quality of gluten is essential in flour for bread-making purposes. If the gluten of flour can be so altered that it is impossible to separate it from the other components and the flour so modified can be used to make bread of good texture (which has been actually demonstrated in the above experiment) then it follows that the theory, that the gluten retains the gases in panary fermentation, is wrong and can not be supported by fact. Inasmuch as flour in which the gluten has lost its ductility and coherence is still suitable for making bread, there are two possibilities as to the relation of gluten to baking quality. Either the gluten in the flour is or is not necessary for the making of bread, regardless of its physical condition.

CONCLUSIONS

Part One (a).

Samples of flour received from mills located in the States of New York, Michigan, Minnesota, North Dakota, South Dakota, Iowa, Kansas, Utah, Montana, Colorado, Texas and Washington were subjected to chemical analyses and baking tests.

A comparative study of the results for chemical and baking tests tend to show that there is no relation between the quality of flour and the following:

1. The total nitrogen.
2. The alcohol-soluble protein components.
3. The gluten content.
4. The water-soluble solids.
5. The acidity.

Neither were relations between the gluten content and the water-retaining qualities of flour observed.

Although no conclusions could be drawn the volumes of the loaves appeared to be inversely proportional to the gluten content.

A loaf of bread having an apparent specific gravity 0.25 or less may be regarded as a satisfactorily baked loaf.

Part One (b).

The irregularities noted in the nitrogen-free and ash-free extract content of flours giving the same and different volume capacities indicate that the nitrogen-free and ash-free extracts do not bear the relation to volume that would be expected according to theory.

There is strong evidence supporting Wood's theory that the ratio of soluble-ash to total nitrogen determines the shape of the loaf. Our experiments indicate that the nature of the electrolytes contained in the soluble ash may have something to do with the property of shape and this may account for the irregularities noted.

The baking quality of flour was not perceptibly affected by the addition of lactic acid at the rate of 0.54 grams per 100 grams of flour; the addition of the mentioned amount of acid, however, did affect the amount of gluten that could be separated from the flour. The significance of modifying the quality of the gluten and its unnoticeable effect upon baking quality should not be overlooked.

The removal of the 70 per cent alcohol extractives from flour impaired the baking qualities of the flour to the extent that it was impossible to obtain a satisfactory fermentation of the dough.

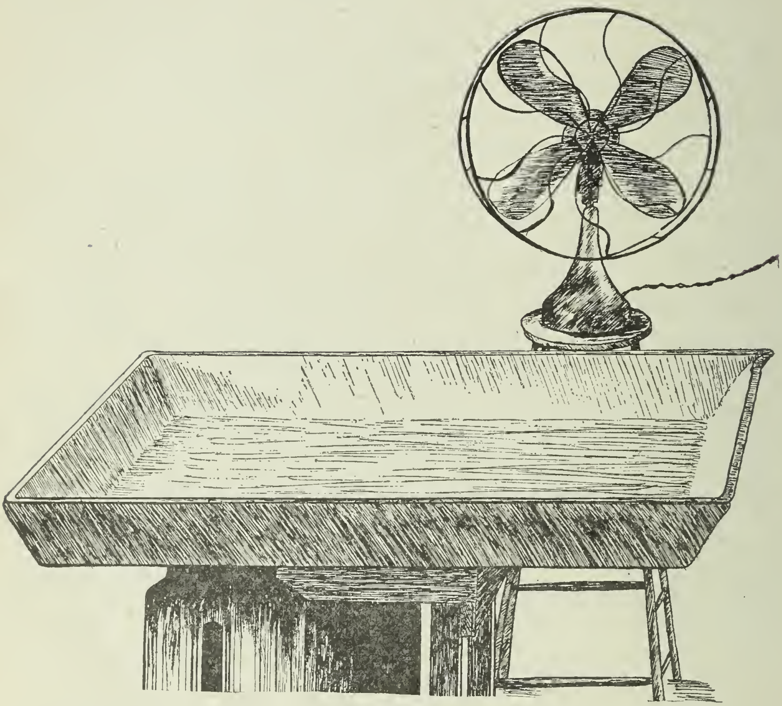
Flour in which a part of the soluble salts had been removed thru the process of dialysis also gave unsatisfactory fermentation action when compared with the same flour untreated.

PART TWO

Progress Report on the Influence of Various Components Contained in Flour on Baking Quality.

The investigations with reference to the importance of the various components of flour have developed some very important and interesting results, as will be seen from what follows.

In earlier work the writer discovered that flour could be treated with large quantities of water and that the flour could be recovered again from the water. This discovery led to some very interesting experiments with reference to



Apparatus used for the drying of the modified flours.

the study of gluten. It has also been of considerable importance in the way of preparing flours for the work contained in this article.

The process consists of evaporating the water at a rapid rate and at a low temperature. A vacuum pan with an agitator perhaps might have been as efficient, but we did not possess anything of this kind suitable for the work involved. In connection with this work large porcelain or stone trays, placed over the radiators, and a 16-inch electric fan, were used. The fan was so placed as to cause the flour and water mixture to move in a rotary fashion. The mixture was occasionally stirred thoroly by hand. The operation was continued until the entire mass could be crumbled into particles ranging from ½ to 1 inch in diameter. The nearly dry material was then ground by a special laboratory mill (26, 29) to the size of clover seed, when it was further dried, then ground and bolted into flour.

It is evident from what has been said above that such a process can only be conveniently carried thru during the cold weather and when there is steam in the radiators. The temperature of the flour and water mixture would be too high if it were not for the fan and it has been possible with its use to keep down the temperature to 15 degrees C. During the drying process chloroform was used to check bacterial action. The time required would vary with the amount of water used in the mixture. When the mixture had lost sufficient water to make the mass of proper consistency it was found advantageous to roll the dough into thin sheets, the completion of the drying becoming more rapid with decrease in thickness of the sheets. The illustration in this picture is a free-hand drawing of the apparatus which was independently devised but which is similar in some respects to the Buxton and Beebee apparatus (7). With such a device at command it has been possible to dry dough flours, and the water extracts from flour, as well as combinations of starch with gluten, starch with water extract from flour, etc.

The milling operation was done with the special laboratory mill and bolting machine described in Bulletin No. 100 of this Station. The last coarse material, which is very refractory to grinding, is softened by moistening with suf-

ficient water, allowed to stand one-half hour, and then milled and bolted to the desired fineness.

It would appear possible to determine the importance of the different components of flour in determining bread-making qualities by the process of eliminating different groups of substances, provided that the process involved does not in any way affect the remaining components. Thus, if a flour is thoroly soaked with distilled water and the supernatant liquid repeatedly removed, the product remaining would be largely composed of insoluble materials, such as insoluble ash, starch, fat, and gluten, while the soluble materials, such as edestin, leucosin, sugar, etc., would be eliminated. Again, if the soluble materials removed by decantation were saved and mixed with starch or other inert substances, dried and reduced to a material suitable for baking purposes, it would make it possible to study the importance of these water-soluble materials and their effect on baking quality. Or, reversing the process, the gluten can be removed and the other components studied in the absence of gluten, while these latter materials can be incorporated with some inert substance such as starch, etc., and the effect of gluten on baking quality thus determined. With the discovery of a process for handling the wetted material it has been possible to study to a limited degree the baking qualities of the several products prepared by such processes of elimination as have just been mentioned.

Methods.

Flour with the Water-Soluble Components Removed.

One of the first trials was with the residue obtained by removing the water-soluble extract by decantation. For this experiment and subsequent ones, the flour was thoroly mixed with sufficient distilled water to give a column of liquid at least twice as great as the volume of the flour paste. After standing in an unheated room (in winter) for 12 hours the supernatant liquid was removed and the insoluble residue was treated a second time with distilled water and let stand another 12 to 24 hours. In some cases the insoluble residue was treated a third time with distilled

water, but in most of the experiments this extra washing with distilled water was considered unnecessary. The residue was collected, in some instances filtered on Buchner funnels, and finally stirred and dried in the manner described in the process mentioned above. It was then milled and bolted to proper fineness.

Combination of the Water-Soluble Extract and Wheat Starch. The water-soluble extract obtained by decantation in the preceding experiment was mixed with purified wheat starch prepared from flour, dried by the process described, rolled, crumbled, and reduced to flour. The amount of starch used was equivalent to the amount of flour used for the extraction of the water-soluble components of flour.

Flour with the Gluten Removed. The most difficult flour to prepare was that from which the gluten was removed. The flour was made into a thin dough with distilled water, allowed to stand for one hour when it was treated with as little water as could be conveniently used to separate the gluten, in order that the amount of water to be subsequently evaporated might be kept as small as possible. The components removed by this treatment were evaporated on the dryer, crumbled, and finally reduced to flour.

Combination of Wheat Gluten and Wheat Starch. In order to make flour from a combination of gluten and wheat starch it was necessary to employ a somewhat different method of procedure from that used with the other combinations. This can readily be understood when one considers the elastic, coherent properties of gluten, which does not lend itself readily to direct mixing.

Prepared wheat starch was moistened with one-half its weight of water and to this the wet gluten was added and the whole placed in the dough-kneader. In the first trial the gluten and starch was at first more or less difficult to mix, but by continuing the operation and adding more water until the quantity of water totaled approximately one-half of the weight of starch the two materials could be blended into mass in less than five minutes time. The prepared dough was then rolled out and dried, crumbled, and finally reduced into flour. The quantity of starch used was such that the gluten in the combination was equal to the quan-

tity obtained from the flour under study. A microscopic study of the gluten-starch flour was made with the object of seeing if gluten particles could be detected. It may be of interest to learn that the mixing of the gluten with the starch was so thoro that it was impossible to detect even traces of gluten in the blend when subjected to a microscopic examination. Nevertheless, upon making a gluten determination from the prepared flour it was found that the gluten could be separated quantitatively. A mixture of quartz flour and gluten was made as described for the wheat starch and gluten combination, and in this preparation also the gluten failed to be visible under the microscope, but could nevertheless be separated from the quartz.

Combination of Wheat Gluten and Corn Starch. In another trial corn starch was substituted for wheat starch with similar results as described in the process for preparing the wheat starch and gluten combination.

Thus by an entirely new method of procedure, it has been possible to make a series of preparations consisting of flour with the water-soluble extract removed, flour with the gluten removed, and starch admixed with the water-soluble extract of whole flour and pure gluten. All of these worked up into flour of lighter color than the original flour used in preparing the material or any other that has come to the writer's notice. The wheat starch combinations were not as sharp* as those with corn starch. Those containing the gluten were more difficult to grind than those not containing gluten and were also sharper than those without gluten. In all instances the flour was sharp, the glutenous ones being very sharp. Expert millers who have inspected some of the prepared flours were of the opinion that they possessed the qualities sought for in the present-day methods of milling, that is, they were pure white, granular flours.

Baking Tests.

Each of the flours prepared as described above were subjected to baking tests.

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*Refers to a gritty granular nature detected by rubbing the flour between the fingers.

Flour with Water-Soluble Extract Removed. In addition to the flour with the water-soluble extract removed, a combination of this flour with 5 grams of a syrupy mass obtained by repeatedly boiling down and filtering the water-soluble extract from flour, a second combination with 1 gram of dextrin and a third containing 0.1 gram of Merck's malt diastase, were used. The same amounts of yeast, salt, sugar, and water were used in each case. The dough was thoroly mixed, fermented and baked. The volume was determined by the use of shot. The results are as follows:

TABLE NO. XIII.

Baking Tests with Flour Having Water Soluble Extract Removed.

	With addition of 5 grams of Syrupy extract	With addition of 1 gram of Dextrin	With addition of 0.1 gram of Diastase	Control
Weight of dough gms.	180.2	176.1	179.6	172.5
Volume of loaf, cc.	274.6	214.6	258.4	214.3
Per cent water used	75	75	75	75

The results recorded in Table XIII show that the syrup made by concentrating the water-soluble extract of flour is a desirable component as is diastase, since the loaves resulting from the addition of these materials are larger than those made from flour deprived of water-soluble extract or such flour plus dextrin. The addition of dextrin in this experiment failed to show any improvement in the volume of the loaf.

Combination of Gluten with Wheat Starch. Baking tests of the flour made of wheat starch plus gluten, also of the combination of this flour with 6.13 grams of syrupy water-soluble extract from flour, and of another containing 0.5 grams of Merck's diastase, were made. The same amounts of yeast, salt, sugar and water were used in these tests. Shot was used to determine the volumes. The results of this baking test are recorded in Table XIV.

TABLE NO. XIV.

Baking Tests with Flour Made from Wheat Starch and Gluten.

	With addition of 6.13 grms. Syrupy Ext.	With addition of 0.5 grams Diastase	Control
Weight of dough, grms	170.0	171.15	173.9
Weight of loaf, grms.	140.5	136.9	141.5
Volume of loaf, cc.	213.6	233.7	213.8
Per cent water used	75	75	75

As was the case in the experiment recorded in Table XIII, it will be noted that the addition of diastase to the combination of wheat starch and gluten has also had a tendency to increase the volume of the loaf in this series. The addition of the syrupy extract of the water-soluble part of the flour did not produce any improvement in this flour in so far as the baking quality is concerned.

Combination of Gluten with Corn Starch. The flour made from the corn starch and gluten was subjected to a baking test. The same flour in combination with 6.13 grams of water-soluble syrupy extract, and with 0.5 grams of Merck's diastase was also used. The same amount of yeast, salt and sugar were used as in the preceding experiment. The amount of water required for the flour in combination with syrupy extract was 5 c.c. less than in either of the other two. The results are recorded in Table XV. Shot was used to determine the volume.

TABLE NO. XV.

Baking Tests with Flour made from Corn Starch and Gluten.

	With addition of 6.13 grams Syrupy Ext.	With addition of 0.5 grams Diastase	Control
Weight dough, grms.	163.2	171.1	167.5
Weight of loaf, grms.	136.3	142.7	163.2
Volume of loaf, cc	186.6	140.1	133.3

Whether or not corn starch is in itself an undesirable component is as yet undetermined. From the results obtained with the corn starch and gluten combination, it appears that it may influence the baking quality. A study of various starches in combination with gluten may reveal the importance of starch in breadmaking. The results for the flour made of corn starch to which the syrupy extract had been added are the reverse of those obtained for wheat starch.

Flour From Which Gluten Has Been Removed. Baking tests were made with the flour prepared after removing the gluten. Another sample of the same flour was used in combination with 2 c.c. of fresh egg albumin. Only 50-gram lots of flour were used and only one-half the amounts of yeast, salt and sugar were used in these experiments as were employed when 100-gram lots of flour were baked. The first trial with this flour was unsatisfactory owing to the fact that it was found difficult to determine the proper amount of water to use. Approximately a 65% water mixture gave surprisingly good results. It may be well to state that the dough mixture made from this prepared flour was of a physical character entirely different from doughs made from any of the other above mentioned flours and especially those containing gluten. By using high-walled tins the dough fermented rapidly and baked out into loaves of bread, which were slightly more porous in texture than bread made from the untreated flour from which this preparation was made. As in preceding experiments of this series, shot was used to measure the volume. The results are as follows:

TABLE NO. XVI.

Baking Tests with Flour with Gluten Removed.

	2 cc. fresh Egg Albumen Added	Control No Albumen Added
Weight of dough, grms.	83.9	80.5
Weight of loaf, grms.	68.7	64.1
Volume of loaf, cc.	137.0	124.5
Per cent of water used	65	60

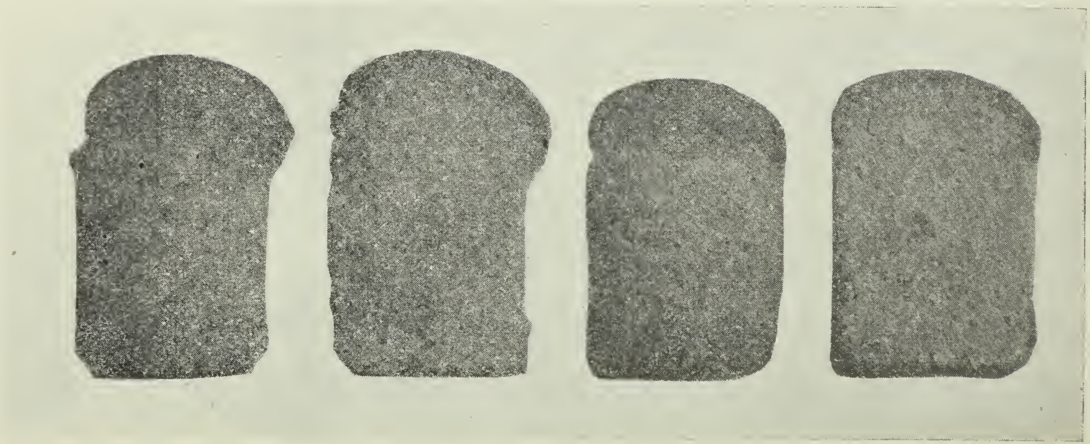

Fig. 10. Bread made from gluten-free flour. Two on left contain egg albumin. Two on right are practically free from nitrogenous material.

The result presented in Table XVI is only one of a series which have been obtained in making bread from gluten-free flour. Similar results have been obtained in using flour made from wheat starch in combination with the water-soluble extract from flour. The reinforcing of the flour with a small quantity of fresh egg albumin improved the volume of the loaf compared to the one without the albumin. (See Fig. 10.)

What the Baking Tests of the Prepared Flour Show When Considered Collectively. In the following table the results for the baking tests of the prepared flour without the addition of either the syrupy water extract or diastase have been arranged for comparative study. As only one-half the usual amount was used in the tests of gluten-free flour the figures for this substance have been multiplied by two so as to give a basis for comparisons with the other flours.

TABLE NO. XXVII.

Comparative Results of Baking Tests with Different Prepared Flours.

	Water Soluble Extract Removed	Wheat Starch & Gluten	Corn Starch & Gluten	Gluten Free with Egg Albumin	Gluten Free	Control Untreated Flour
Weight dough grms.	172.5	173.9	167.5	167.8	161.0	156.2
Weight loaf grms.	......	141.5	134.1	137.4	128.2	135.5
Volume of loaf cc.*	214.3	213.8	133.3	274.0	249.0	225.
Per cent water used	75	75	75	65	60	52

*Measured with lead shot. Based on 100 grams of flour.

The results in repeated trials of the gluten-free flour have not shown marked variations from those recorded in Table XVI. On the other hand, the results for the gluten-free flour with the water-soluble extract removed together with the combination of starch and gluten in the earlier experiments were usually more in accord with those obtained with the corn starch and gluten combination. With the exception of the corn starch-gluten combination, the results obtained for the various combinations are equal to or better than those for the flours from which the combination flours were prepared. The largest volumes obtained were

with the gluten-free flour with and without fresh egg albumin. The water absorption of the prepared flours was also higher in all cases than that of the control flour. The fact that a loaf of bread of as good texture was made from the flour without the gluten as was possible to get with the flours containing the gluten combinations, considered in connection with the results presented in another part of this bulletin with the flour in which the physical properties of the gluten had been modified by the addition of electrolytes, suggests, if it does not prove, that gluten as gluten does not play the role in panary fermentation or baking which has been generally ascribed to it.

The writer's address, "Is Gluten Necessary for the Making of Good Bread?" before the Operative Millers' Association at Detroit, Mich., in June, 1911 (28), was based upon investigations such as those described above.

The methods employed in preparing the flours described above have been very satisfactory. In a more extensive study it is believed that the influence on baking quality of the various components of flour can be determined.

The above investigations cover only a small part of a possible large field of study along this line. Various factors must be taken into consideration in a work of this kind, e. g., the effect that such a process may have upon the original product, the method of control, handling of the flour, the desirable compared to the undesirable combinations, the influence of various salts, etc. Thus in these investigations, tho progress has been made, their correct value can not be determined until it has been possible to construct a flour equal in quality to those milled directly from wheat and under all the conditions to which flour is subjected in the practice of panary fermentation.

Investigations have been initiated with a view to determining the importance of each and every group that makes up the various components of flour. The work accomplished is far from complete and only thru careful and painstaking work will it be possible to present the matter in its true light.

It might be well to include a series of investigations which have been performed during the past year. The methods of preparing the flour are practically identical with

those already presented. In this investigation it was considered desirable to compare the flours soaked in water and reconstructed into flour again with the same flour not treated.

Baking tests were made of the untreated flour, flour soaked in water, wheat starch in combination with water-soluble extract of flour, wheat starch in combination with gluten, flour with water-soluble extract removed, and a mixture of equal amounts of each of the wheat starch gluten flour and the wheat starch flour mixed with the water-soluble extract. The same quantities of yeast, salt and sugar were used in all cases, while the water absorption varied with the different flours. The physical conditions of the doughs of the prepared flours were somewhat different, and not in any case exactly like that from the original flour untreated or treated with water. The gluten-free preparations of flour, the wheat-starch combination with the water-soluble extract, also the equal blend of wheat starch flour, and water soluble and gluten combinations, were quite different from any of the other combinations in the series.

The results of the baking tests of this series are reported in Table XVIII. The volumes were measured in this series with German millet seed and not with shot as had been done in the preceding experiments. Only 50 grams of flour were used in each case.

TABLE NO. XVIII.

Baking Tests with Prepared Flour Compared With Flour Modified by Water and Control not Modified

No. 1 Control Not Treated—	
Weight of dough, grams	86.4
Weight of loaf, grams	73.4
Volume of loaf, cc.	230.
Per cent water used	70.
No. 2 Treated with Water—	
Weight of dough grams	92.0
Weight of loaf grams	81.3
Volume of loaf, cc.	225.
Per cent water used	82.5
No. 3, Starch and Soluble Extract—	
Weight of dough, grams	89.0
Weight of loaf, grams	73.1
Volume of loaf, cc.	220.
Per cent water used	79.

No. 4, Starch with Gluten—	
Weight of dough, grams	96.9
Weight of loaf, grams	77.7
Volume of loaf, cc.	120.
Per cent water used	94.
No. 5, Water Extract Removed—	
Weight of dough, grams	84.6
Weight of loaf, grams	68.4
Volume of loaf, cc.	130.
Per cent water used	77.4
No. 6, Starch with Gluten and Water Extract—	
Weight of dough, grams	97.9
Weight of loaf, grams	82.9
Volume of loaf, cc.	200.
Per cent water used	95.3
No. 7, Without Gluten—	
Weight of dough, grams	97.4
Weight of loaf, grams	81.2
Volume of loaf, cc.	150.
Per cent water used	95.1

The results obtained and recorded in Table XVIII are not very different from those given in Tables XIII, XIV, XV, XVI, and XVII, altho the flour is entirely different from that used in the experiments for which these tables give data. The difference observed in the volumes is due to the method of measuring and the volumes in the series under consideration can only be compared with each other. Those in Tables XIII, XIV, XV, XVI, and XVII were measured with small shot, while these (Table XVIII) have been measured with German millet seed. The volume for starch with water-soluble extract of flour No. 3 compares with the untreated No. 1 and treated No. 2 flour. The results for the flour without the gluten No. 7 do not show as high values, but are nevertheless, higher in volume than either the flour without the water-soluble extract No. 5 or the flour made from starch and gluten No. 4. It is rather difficult to draw definite conclusions, but it seems quite clear to the writer that the water-soluble extract contains a substance or group of substances which are very important in determining volume. The importance of the individual substances in the water-soluble extract in effect on baking quality is as yet not known. Baking trial No. 6 shows what influence the water-soluble

extract prepared flour has had on the starch and gluten combination.

TABLE NO. XIX.

Further Baking Tests Made with Some of the Flours in Table XVIII.

No. 8, Treated with Water—	
Weight of dough, grams	88.0
Weight of loaf, grams	73.5
Volume of loaf, cc.	190.
Per cent water used	77.4
No. 9, Water Extract Removed—	
Weight of dough, grams	98.4
Weight of loaf, grams	85.3
Volume of loaf, cc.	160.
Per cent water used	97.0
No. 10, Without Gluten—	
Weight of dough, grams	97.0
Weight of loaf, grams	82.9
Volume of loaf, cc.	180.
Per cent water used	95.0
No. 11, Starch with Gluten—	
Weight of dough, grams	109.4
Weight of loaf, grams	88.9
Volume of loaf, cc.	140.
Per cent water used	120.0

In the last baking test, in which an increased amount of water in the dough was used, the result was an improvement of the flour with the water-soluble extract and the starch and gluten combination (see Nos. 5 and 9, also 4 and 11). They are, however, not as high in volume as the flour without the gluten (see No. 10), which is an improvement over No. 7.

The texture of the loaves varied considerably, the best in the series was that made of the untreated flour, which is followed by the flour treated with water. The texture of the loaves made from the starch and water-soluble extract flours was somewhat open but very even, while the gluten flour combinations were very compact. In this series of bakings it can not be said that the texture was as good in the water-soluble extract starch combination as was the case in the earlier work. On the other hand, the volumes of numbers 1, 2 and 3 are within the usual range of variation of a sample of flour. All the prepared flours that the writer

has made require more water for successful baking than is required with flours from which no components have been separated.

Inasmuch as the nitrogenous components of flour have always been considered important in connection with baking tests, the writer believes that it is not out of place to present such data concerning the nitrogen and gluten composition of the prepared flours as might prove of interest in connection with the baking tests which have been presented in the preceding pages.

Analyses of the various prepared combinations compared with the normal untreated flour for total nitrogen, total alcohol-soluble nitrogen, total alcohol-coagulable nitrogen, nitrogen precipitated by phosphotungstic acid, wet and dry gluten and the nitrogen in the gluten were made with the following results:

TABLE NO. XX.

Comparison of Results for Nitrogen Content of Prepared Flours.

	Control Not Treated	Water Extract Removed	Gluten Free	Corn Starch with Gluten	Wheat Starch with Gluten
Per cent Total Nitrogen	1.54	1.32	0.275	1.85	1.73
Per cent Alcohol Soluble Nitrogen	0.90	0.94	0.01	1.12	1.08
Per cent Alcohol Soluble Coagulable Nitrogen	0.47	0.48	......	0.55	0.43
Per cent Phosphotungstic acid precipitated Nitrogen	0.40	0.35	......	0.43	0.55
Per cent Wet Gluten	17.6	.....	......	21.7	27.9
Per cent Dry Gluten	6.21	.....	......	9.18	10.09
Per cent Nitrogen in Gluten	14.04	.....	......	9.95	11.90

Ratio of Dry to Wet Gluten—
- Control not treated 1:2.83
- Water extract removed ....
- Gluten free ....
- Corn starch with gluten 1:2.36
- Wheat starch with gluten 1:2.76

Comparing the results obtained in Table XX, especially for the normal, that having the water-soluble extract removed and that which was gluten-free, it will be noted that the nitrogen has decreased in the order named, being slightly lower for the one where the water-soluble materials were

removed and only one-sixth as much in the gluten-free as in case of the original. The prepared flours made up of corn starch, wheat starch and gluten contained somewhat larger quantities of nitrogen than was found in the normal, due to the incorporation of a larger quantity thru the addition of the wet gluten which varies more or less in its purity as separated from flour. In regard to the alcohol-soluble nitrogen the quantities obtained vary according to the treatment which the flours received. It may be said, however, that the process involved in preparing the flours has not appreciably affected the total alcohol-soluble nitrogen nor its proportional separation into coagulable and non-coagulable alcohol-soluble portions. It is to be expected that when the gluten is removed, little or no alcohol-soluble nitrogen would be present and this was found to be the case in the gluten-free flour. The quantity and purity of the wet and dry gluten was quite variable in the case of the prepared gluten starch flours as compared with the normal untreated flours. The writer has pointed out the fact that the removal of the water-soluble extract also prevents the gluten from being separated from flour and this experiment gives additional data in this respect, yet, as can be seen from the figures for total nitrogen and those for gliadin nitrogen, the components gliadin and glutenin are unquestionably present.

Further work upon these lines is contemplated, and it is hoped that the part which the different components of flour play in panary fermentation may be disclosed in the not distant future.

CONCLUSIONS

Conclusions are reserved subject to further investigational work. Some results which have been obtained may be briefly summarized and are as follows:

The water-soluble extractives from flour were added to both wheat and corn starch with beneficial results in volume production. Flour from which the gluten was removed gave similar results.

The addition of gluten to both wheat and corn starch resulted in forming compact, rubbery masses. Flour from

which the water-soluble extractives were removed also resulted in forming compact masses.

The addition of the water-soluble extractives to flour made up of either wheat starch and gluten, or corn starch and gluten resulted in increased volumes, but these were not equal to the volumes obtained by mixing the water-soluble extractives with both the wheat starch and corn starch or flour from which the gluten had been removed.

While it is true that the significance of the water-soluble and gluten component of flour to baking quality are shown to a certain extent in our experiments it is impossible at this writing to express the exact importance of each. The progress of the work is continuing satisfactorily.

PART THREE

The Milling Value of Water-Soaked Wheat.

A few years ago flood waters caused the damage of considerable quantities of wheat stored in the warehouses at Pullman, Washington. As studies of the milling and baking qualities of wheat and flour were at that time in progress in the author's laboratory, it was thought that germination of such wheat might throw light upon the problem, and at the same time determine whether or not wetting has any detrimental effect upon baking quality of flour subsequently made from the wheat.

To what extent water can damage wheat was not definitely known at that time. None of the wheat was to be used for seed purposes, therefore viability was obviously of only secondary interest. The molding of moist wheat was followed by undesirable chemical changes which rendered the wheat unfit for feeding or milling purposes. Aside from these chemical changes there is a natural tendency for wheat to sprout and grow until the wheat transforms into plantlets which finally cease growing unless the rootlets reach into fertile soil. Heating and sprouting are therefore natural sequences of the wetting of grain, and the extent to which these processes affect the milling qualities of wheat are worthy of consideration.

In the process of malting, barley is first soaked with

water, spread evenly on floors and then allowed to heat uniformly and grow until the plumule (epicotyl) reaches a fixed length, the amount of growth depending upon whether the grain is to be used for brewery or distillery purposes. When the plumule reaches the desired length, the growth is suddenly checked by drying the sprouted grain in dry kilns, resulting in what is known as malt.

Malt or its products have been combined with flour in a number of ways for baking purposes. Sometimes malt extract (a condensed converted extract of malt) has been used to change the flavor of the bread or to stimulate the yeast growth in the rising of the dough. In other cases the enzyme diastase (a ferment in malt which has the power of transforming large quantities of starch into sugar under favorable conditions) has been used. This enzyme in the form of a cold water infusion of malt acts upon the starch of wheat and results in its conversion. Sometimes maltose (the sugar formed from malt in the process of conversion) has been used. In other instances small quantities of malt have been blended with the wheat and milled, resulting in a flour containing a limited quantity of malt flour and at least one patent (U. S. Patent No. 839,889) covering such a process has been issued.

That the addition of any one of the malt products to flour has a beneficial effect upon the rising of the dough has long been recognized. Wheat can be made into wheat malt in the same way that barley is made into malt. Its use in the distilleries and breweries has resulted in inferior products and for that reason only limited amounts have been used for this purpose. The use of wheat malt in flour-making has not been studied. In place of using the dry kiln for drying germinated wheat, the writer thot that air drying or the use of the heaters frequently used in treating new wheat would aid in preventing chemical changes in the proteins.

In consequence of the large quantities of wheat that frequently spoil under conditions similar to those described above, a series of investigations were conducted; first, to determine the changes that occur in the protein constituents; second, to ascertain the effect of germination upon the yield of flour; third, to discover the loss in weight of grain

due to germination; fourth, to determine the baking qualities of the resulting flour; and, fifth, to ascertain the beneficial or prejudicial effect upon the baking qualities of flours to which small quantities of flour from germinated wheat have been added.

The first experiment was as follows: Series of three lots each of wheat were soaked and allowed to germinate as follows: the one lot germinated and grew until the plumule was equal to one-fourth the length of the kernel, the second grew until the plumule was equal to the length of the kernel, and the third lot grew until the length of the plumule was twice the length of the kernel. After the wheat had reached the specified limit of growth, each lot was spread thinly over a smooth surface and with occasional stirring was allowed to air dry in the room for approximately five days. The dry samples were next weighed to determine the loss due to soaking and growing, and finally ground into the milling products, flour, bran and shorts. The influence of germination upon yield of flour was also noted. The effect of soaking, germinating, and drying of Bluestem, Mixed and Spanish wheats are recorded in the following table:

TABLE NO. XXI.

Decreased Yield of Wheat due to Various Stages of Germination.

Length of Epicotyl	Length of Kernel	Bluestem		Mixed		Spanish	
		% wt.	% loss	% wt.	% loss	% wt.	% loss
¼	1	99.40	0.60	99.45	0.55	100.85	0.85*
1	1	97.30	2.70	96.60	3.40	98.60	1.40
2	1	96.30	3.70	95.00	5.00	96.95	3.05

*Gain.

It will be noted from the data given in Table No. XXI that the losses are not uniform with the different wheats under investigation. The largest loss occurred in the Mixed variety, where the plumule had reached twice the length of the kernel. The Spanish hard wheat gave uniformly lower results than either of the other two varieties mentioned.

The results on milling tests of the germinated wheats

under investigation are recorded in Table No. XXII.

TABLE NO. XXII.

Distribution of Milling Products as Affected by Germination.

Bluestem—

Length of Epicotyl to Length of Kernel	% Bran & Shorts	% Flour	% Loss
Control	23.35	74.15	2.55
¼=1	29.30	67.10	3.00
1=1	36.40	59.55	1.39
2=1	41.20	51.70	3.53

Mixed—

Length of Epicotyl to Length of Kernel	% Bran & Shorts	% Flour	% Loss
Control	25.80	72.60	1.60
¼=1	33.70	60.00	5.78
1=1	34.40	56.85	5.86
2=1	32.10	55.90	7.39

Spanish—

Length of Epicotyl to Length of Kernel	% Bran & Shorts	% Flour	% Loss
Control	38.77	60.55	1.53
¼=1	50.75	40.70	5.39
1=1	59.65	35.00	4.00
2=1	56.70	31.60	8.92

From the data given in Table No. XXII it will be seen that germination has influenced the yield of flour, which decreased without exception as the length of the plumule increased. The bran and shorts in the Bluestem and Spanish, and to a slight extent in the Mixed variety of wheat, increased as the length of the plumule increased. The percentage losses in the milling were more marked in the Mixed and Spanish wheats than was the case with the Bluestem.

The germinations of the grains is accompanied by the production of the enzyme diastase, the amount of diastase increasing with the length of time the grain is allowed to

germinate, up to a certain limit. The writer, therefore, next determined the diastatic power of the flour made from germinated wheats as compared with flour from the same wheat ungerminated. The time required to convert its own starch (using iodine as an indicator) was used as a relative value of the amount of diastase contained in the flour. Five-gram lots of the respective flours were treated with 100 cc. of water (70 deg. C.) and kept at this temperature until the iodine failed to give the characteristic color for starch. The time required for these conversions are as follows:

TABLE NO. XXIII.

Diastic Power of Germinated Wheat.

Length of Epicotyl to Length of Kernel	Bluestem No. 1 Minutes	Bluestem No. 2 Minutes	Mixed Minutes	Spanish Minutes
	Not in	Not in	Not in	Not in
Control	480	480	480	480
¼=1	180	45	55	75
1=1	70	40	42	45
2=1	55	30	25	35

The data given in Table No. XXIII shows different time requirements for the conversion of the starch in the germinated wheats compared with the control. The writer failed to obtain complete conversions of the control in periods as long as eight hours, indicating that diastase acts very slowly in wheats which have not been wetted. For each variety of wheat the time required for the conversion of starch decreased as the length of the plumule increased.

The effect of germination on the gluten content of the flour was also studied. Ten gram samples of the control and germinated wheat flours were worked up into uniform masses with six cubic centimeters of water and after standing for periods of one hour were washed under running water in order to remove the starch from the gluten. The glutens were collected on weighed filter papers and allowed to dry until constant weight was attained. The weights of the glutens were then determined and are as follows:

TABLE NO. XXIV.

Effect of Germination on Yield of Gluten.

Length of Epicotyl to Length of Kernel	Bluestem No. 1 % Dry Gluten	Bluestem No. 2 % Dry Gluten	Mixed % Dry Gluten	Spanish % Dry Gluten
Control	14.19	13.40	10.44	13.43
¼=1	11.53	8.92	7.51	9.43
1=1	9.26	3.29	0.38	1.28
2=1	2.06	0.03	0.28	0.38

As will be seen from the results in Table No. XXIV germination very markedly reduces the amount of gluten recovered. The amount of gluten obtained under identical conditions varies with the wheat and the degree of germination. The accompanying cut illustrates in another way the decreased yield of gluten due to germination.

It has been known for a long time that the complex nitrogen compounds decompose into simpler forms during the process of germination of seeds. The fact that the yield of gluten decreases as the length of time allowed for germination is increased indicates that decomposition is in progress. To know just how rapidly the nitrogen complexes change into simpler ones might be of interest and the writer has determined the total, 70 per cent alcohol soluble, 10 per cent salt soluble, and amide nitrogen, and also the glutenin (by difference). The albumin and globulin were precipitated by phosphotungstic acid and the nitrogen remaining unprecipitated in the liquid was reckoned as amide nitrogen. The alcohol-soluble and salt-soluble nitrogen subtracted from the total nitrogen of the flour left a remainder which was considered glutenin. Whether or not the nature of these soluble products is similar in all cases is undoubtedly of great importance, but the writer has not considered this phase of the subject, since it has no direct bearing on the quality of the flour made from the wheat. The per cents of the various nitrogenous products in the respective flours from Bluestem wheat, together with the per cent of total nitrogen, are recorded in Table No. XXV.

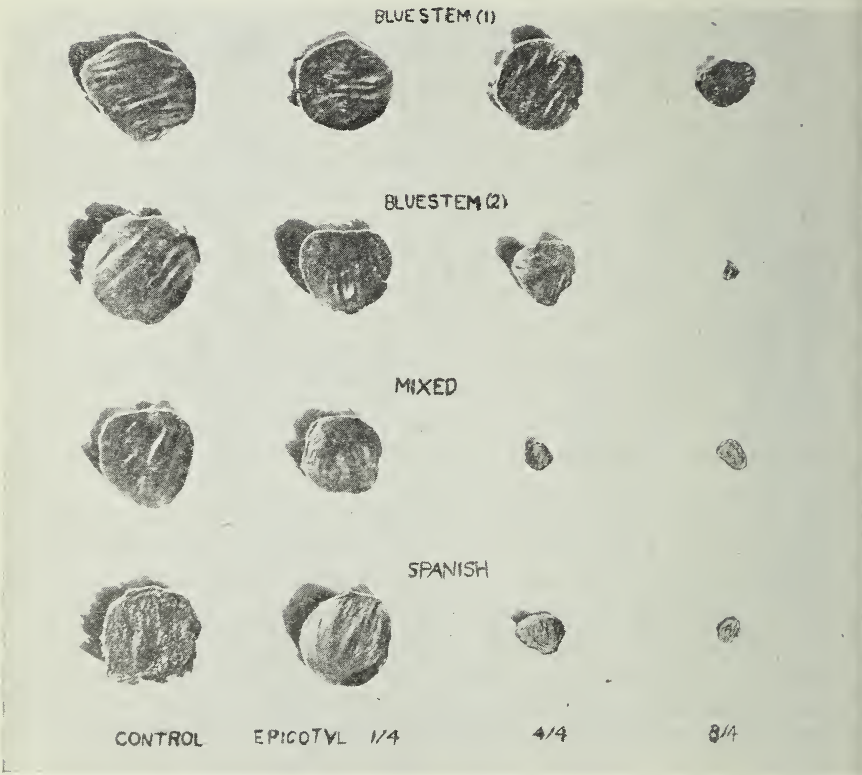

Fig. 11. Prolonging the period of germination of the wheat decreases the amount of gluten that can be obtained.

TABLE NO. XXV.

Nitrogenous Components in Flour as Affected by Germination

Length of Epicotyl to Length of Kernel	% Total Nitrogen	% Gliadin Nitrogen	% Glutenin Nitrogen	% Globulin & Albumin Nitrogen	% Amide Nitrogen
Control	1.77	0.826	0.468	0.476	0.014
¼=1	1.715	0.784	0.558	0.372	0.014
1=1	1.61	0.770	0.378	0.392	0.070
2=1	1.54	0.770	0.098	0.532	0.140
Expressed in per cent of total Nitrogen					
Length of Epicotyl to Length of Kernel	**% Total Nitrogen**	**% Gliadin Nitrogen**	**% Glutenin Nitrogen**	**% Globulin & Albumin Nitrogen**	**% Amide Nitrogen**
Control	100.00	46.66	26.44	26.82	0.08
¼=1	100.00	45.71	32.54	21.67	0.08
1=1	100.00	47.83	23.48	24.35	4.34
2=1	100.00	50.00	6.36	34.55	9.09

The results given in Table No. XXV show that the per cents of nitrogen in flours obtained from germinated wheat are slightly lower than is the case with flour obtained from ungerminated wheat. The flour from wheat which was allowed to germinate for the longest period contained the smallest amount of nitrogen. Expressed in per cents of total nitrogen, it will be interesting to note that the amount of alcohol soluble and amide nitrogen increased with the prolongation of germination, with the amount of albumin and globulin running fairly constant in the different stages of germination. It appears from these facts that the decomposition of gluten due to germination was at the expense of the glutenin originally present. More work will have to be done upon this point before anything definite can be said in regard to this decomposition.

Baking tests of the flour from the germinated wheat were compared with a control of flour from the same wheat ungerminated. The conditions were as nearly alike as possible in all cases. Seven minutes were allowed for kneading

100 grams of flour plus 56 cc. of yeast solution. The length of time required for the rising of the dough, baking, volume of loaf and the apparent specific gravity are recorded in Table No. XXVI. Shape and texture of the loaves are illustrated in the accompanying cut (Fig. 12).

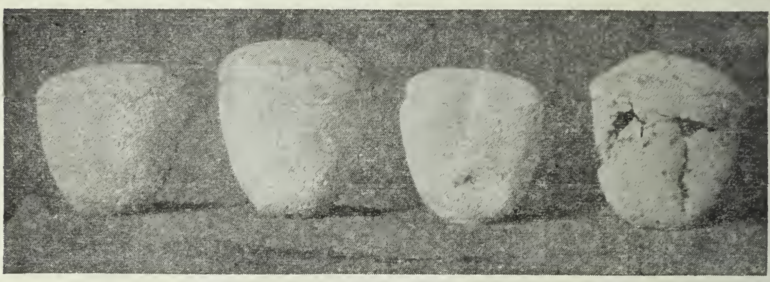

Fig. 12. The loaf to left was made of flour from ungerminated wheat. The second loaf was made of flour from partially germinated wheat. The third loaf from wheat with the plumule equal to length of kernel and the fourth from wheat with the plumule equal to twice the length of the kernel.

TABLE NO. XXVI.

Baking Tests of Germinated Wheat

Length of Epicotyl to Length of Kernel	Time for Rising Minutes	Time for Baking Minutes	Weight of Loaf, grams	Volume of Loaf C. C.	Apparent Specific Gravity
Control	242	30	133.9	260	0.515
¼=1	249	30	137.9	350	0.394
1=1	237	30	130.3	290	0.448
2=1	222	27	?	*	.....

*Burst.

According to the results given in Table No. XXVI it will be noted that flour made from germinated wheat has been benefited in two cases in so far as the rising of the dough is concerned. The accelerating influence on the rising of the dough from No. 3 and No. 4 flours and the retarding influence on that from No. 2 flour are difficult to explain. The amount of diastase present in the wheat flour where the plumule had grown twice the length of the kernel is

Fig. 13. Note the partially collapsed condition of the third loaf and the collapsed condition of the fourth loaf.

slightly more than in the case where the plumule was equal to the length of the kernel. The prolonged time required for the amylytic action in No. 2 flour indicates that very little diastase is formed in the early stages of germination.

Although the data given in Table No. XXVI indicate that germination of wheat results in increased size of loaves in case of No. 2 and No. 3, it is nevertheless true that the texture of the crumb of these loaves was inferior to that of the control, as can readily be seen from the accompanying cut (Fig. 13).

These loaves were sticky to the touch and sweet to the taste. A large amount of the sugar present in No. 4 had undoubtedly been decomposed by the yeast into alcohol, carbon dioxide and other volatile substances, which were driven off in baking, and as a result this loaf had a very small volume.

The effect of adding small quantities of germinated wheat flour to normal flour was next studied. An example of the beneficial influences of adding small quantities of germinated wheat flour are given in Table No. XXVII. (Also see Fig. 14.) The germinated wheat flour used was

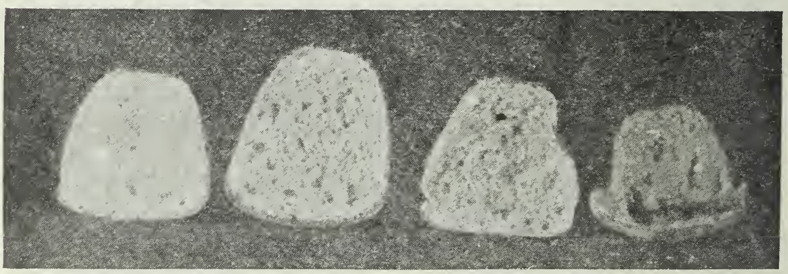

Fig. 14. The effect of adding small quantities of germinated wheat flour to a flour of commercial grade increased the size of the loaf without impairing the texture.

Bluestem No. 1, in quantities of one per cent, five per cent and ten per cent, respectively. Other baking tests were made, using the same quantities of Bluestem No. 2, Spanish and Mixed germinated wheat flours. In order to get good results with these last named flours, it was necessary to use must larger quantities than was the case with the first one.

TABLE NO. XVII.

Influence of Adding Small Quantities of Germinated Wheat Flour to Normal Flour on Size of Loaf.

Normal—			
Length of epicotyl to length of kernel	Control		
Weight of loaf	134.15		
Volume	282.		
Apparent specific gravity	0.48		
Apparent specific gravity (based on 134.15 for weight of loaf)	....		
Per cent volume increase	....		
99% Normal. 1% Germinated—			
Length of epicotyl to length of kernel	¼=1	1=1	2=1
Weight of loaf	134.35	130.9	130.9
Volume	302.	346.	350.
Apparent specific gravity	0.444	0.376	0.372
Apparent specific gravity (based on 134.15 for weight of loaf)	0.444	0.387	0.383
Per cent volume increase	7.09	22.7	24.11
95% Normal, 5% Germinated—			
Length of epicotyl to length of kernel	¼=1	1=1	2=1
Weight of loaf	136.9	137.1	136.6
Volume	368.	368.	362.
Apparent specific gravity	0.374	0.373	0.377
Apparent specific gravity (based on 134.15 for weight of loaf)	0.364	0.364	0.370
Per cent volume increase	30.50	30.50	28.4
90% Normal, 10% Germinated—			
Length of epicotyl to length of kernel	¼=1	1=1	2=1
Weight of loaf	147.8	148.8	149.5
Volume	396.	420.	416.
Apparent specific gravity	0.398	0.354	0.359
Apparent specific gravity (based on 134.15 for weight of loaf)	0.338	0.319	0.322
Per cent volume increase...........	40.4	49.0	47.5

There are several important points to be considered in the data given in Table No. XXVII, viz.: The addition of germinated flour has increased the water-holding capacity in direct proportion to the amount of germinated wheat flour added. The volume of the loaves increased and the apparent specific gravity decreased with the addition of the higher per cents of germinated wheat flours. The vol-

ume of the loaf was increased in one case 49 per cent without impairing the quality of the bread made and there seems to be very little difference when ten per cent of germinated wheat flour is added, whether the plumule was equal to, or twice the length of the kernel. Repetitions gave similar results. The use of another flour gave entirely different results, thus indicating that if it becomes desirable or practicable to use germinated wheat flour in conjunction with other flour, it would be necessary to study each flour independently.

Ford and Guthrie (10) as a result of their studies of the "Amylolytic and Proteolytic Ferments of Wheat and Flour and Their Relation to Baking Value," claim that "the strength of a flour is largely dependent on its capacity for gas formation." Diastase produces sugar and thru the process of fermentation carbon dioxide is developed. The more diastase a flour has, the more sugar it forms, and consequently the more carbon dioxide results. They further state that "the baking quality is proportional to the amount of amylase present." It has been shown in Table No. XXVI (also see Fig. No. 13) that when flours from germinated wheat were used, those that contained the most diastase made the poorest loaves of bread, hence the quality can not be considered proportional to the amount of diastase present. On the other hand (see Table No. XXVII), when limited amounts of diastase or germinated wheat flour are used, the quality of the bread was improved. These results would indicate that diastase is essential to good baking quality.

Neumann and Salecker (25) while studying the influence of malt diastase preparations, found that these preparations when added to flour increased the size of the loaves without impairing the quality. Flours of high gluten content were found to give better results than flours with low gluten content.

Just how much diastase is present in normal flour is difficult to state. Direct extracts of flour and cold infusions of flour extract have failed to convert small quantities of starch, indicating that the amylase, if present, must be limited to extremely small quantities. The writer has not attempted to measure the diastatic power of flour by the

amount of copper reduction or the carbon dioxide formed, since these methods introduce many errors

It appears from the writer's results that, within certain limits, diastase improves the baking quality of a flour. The amount of diastase necessary to make a good baking quality flour depends upon the flour. Too large an amount of diastase is more detrimental to the baking quality of a flour than its entire absence. These results are in accord with H. A. Kohnan's views (21). This author used varying amounts of malt extract in determining the effects of malt upon the strength of a flour and the diastatic power of the malt extract. The strong flours were able to make good bread despite the presence of much larger amounts of malt extracts or extracts of greater diastatic power, while the baking quality of the weaker flours were greatly impaired under similar conditions.

Collectively, the data submitted in this paper clearly indicates that wheat which has been water-soaked can be successfully milled into flour. Even a partial germination does not affect the milling or baking qualities. Wheat which has been water-soaked should be thoroly cleaned and dried, using low temperatures at the outset of the process and finishing with relatively high temperatures. The drying can be done either by spreading the wheat in shallow layers over large surfaces, with frequent stirring to prevent overheating, or by passage thru tubes continually supplied with currents of heated air.

Wheat that has germinated or limited quantities that have been water-soaked, even if the plumule is twice the length of the kernel, can be used to good advantage as a blend to improve flours yielding scant volumes when baked into loaves.

When water-soaked wheat heats and does not germinate, there is a possibility that such wheat has been injured. Conditions similar to this frequently occur, and instead of germination, molding takes place. Such wheat is better for feeding purposes, providing the molding has not been excessive. The best use for wheat in which decided molding has occurred is as a fertilizer, and whenever possible should be hauled to the field for that purpose.

CONCLUSIONS

1. Wheat which has been allowed to sprout loses in weight as the length of time allowed for germination advances.

2. The milling value of germinated wheat decreases as the length of the plumule increases.

3. The length of time required for the conversion of starch decreases as the length of the plumule increases, to at least twice the length of the kernel.

4. The amount of gluten which can be recovered from flour from germinated wheat is less than that from ungerminated wheat. The yield of gluten decreases rapidly as the plumule increases in length.

5. Expressed in per cent of total nitrogen, the alcohol-soluble nitrogen has been affected by the germination of wheat. The most marked changes were observed in the glutenin and amide nitrogen. In the former there was a sudden decrease in amount from the period where the plumule was equal to the length of the kernel to that where the plumule was equal to twice the length of the kernel. The amide nitrogen increased rapidly from the time when the plumule was equal to the length of the kernel.

6. When germinated wheat flour was baked only the quality of the crumb of the bread was impaired; this was particularly noticeable in flours made from germinated wheat in which the plumule was equal to or twice the length of the kernel. The volume of the loaf increased, being exceptionally large in the bread made from partially germinated wheat flour.

7. Using small quantities of germinated wheat flour with other flour, it was found that the volume of the loaf could be increased without impairing the texture of the loaf. Each particular flour requires a different amount of germinated flour in order to produce the best results. Too large an amount of strongly diastatic flour is less beneficial than none.

8. A water-soaked wheat is not necessarily spoiled and can be used for milling purposes, providing it has been thoroly cleaned and dried.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF CHEMISTRY

The Estimation of Sulfur in Plant Material and Soil

By

GEORGE A. OLSON

BULLETIN NO. 145
April, 1917

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The Estimation of Sulfur in Plant Material and Soil

By

Geo. A. Olson, Chemist*

In 1909 a project "Sulfur as Plant Food Material" was approved by the Station Staff. The first work conducted by the division was a study of the sulfur content of various plant food materials as determined according to certain approved methods. Among the methods investigated should be mentioned Osborne's sodium peroxide fusion method (8) Barlow and Tollen's combustion method (1), Parr's bomb method (9), Sherman's modification of Osborne's method (11, 12) and others (2, 3, 5, 7, 10, 13).

In the preliminary work it was found that the Parr bomb method was not only odorless, but eliminated errors due to sulfur contained in the laboratory gas, loss thru ignition in the process of operating, foaming over, and sputtering. Compared with Osborne's method or Sherman's modification thereof, the Parr bomb method gave slightly lower results. The Barlow-Tollens method was considered impracticable owing to the time required for each determination, while Parr's method was very rapid.

The Osborne method gave good results for protein substances such as gluten, casein, etc. On the other hand, the above mentioned method did not give good results when

*It was the expressed wish of the writer that the preparation and presentation of the material contained in this article should have been made by those who were largely if not entirely responsible for the development of the method to the point at which it has now reached. The method should have been presented for publication by the former collaborators, W. L. Hadlock, and Chas. K. McWilliams. The writer is indebted to them for the material contained herein as well as the patience and care exercised in bringing the method to a satisfactory basis.

compared with other methods on such substances as plant materials containing various amounts of silica. Generally speaking the results obtained by the Osborne method were somewhat higher than those obtained by the Sherman modification when the silica was removed by the process of dehydration. The official method (7) adopted by the Association of Official Agricultural Chemists does not include the process of dehydration and separation of silica. Parr, supporting Hillebrand's views (6), considers it unnecessary to dehydrate silica in a solution measuring 200 to 300 cubic centimeters.

The results obtained in following the sodium peroxide fusion method in comparison with the Parr method varied considerably. We interpreted the variable results obtained as indicating that something which is undoubtedly of importance has been overlooked in the process. In our investigations we made hundreds of determinations using variable quantities of hot and cold barium chloride in various amounts of solution having different degrees of acidity. After the method was perfected it was found that the Parr method gave reliable results when compared with other approved methods. We account for the variations in the results previously noted as being due to several causes. The main reason why we obtained low results with the bomb method in the earlier experiments was due to the failure to reduce the plant or soil material to a suitable degree of fineness. The coarse material invariably was only reduced to a partially burned mass and the sulfur contained in these carbon particles was evidently lost by reason of the incomplete combustion of the coarse material. Another possible cause for low results may be a loss of part of the asbestos filtering mat. High results we believe are due to the failure to remove the last traces of the chloride which exists either in the absorbed condition or in combination with the barium sulfate precipitate, and in the earlier experiments some high results were due also to the inclusion of silica.

Working with a specially prepared dry gluten of suitable fineness, Mr. McWilliams (Table I) obtained an average of 2.202% of sulfur trioxide with the bomb method compared with 2.165% of sulfur trioxide by the Haywood method and 2.175% of sulfur trioxide by the Osborne method. With a specially prepared ashless casein dried at 100° C., the

TABLE I.—Results obtained by the Parr method for sulfur trioxide compared with the Official (Haywood) or Osborne method.

Substance	Parr Per cent SO_3	Haywood Per cent SO_3	Osborne Per cent SO_3
LINSEED MEAL—			
Average (5 det.)	1.116	(2 det.) 1.123	.....
Maximum	1.140	1.170	.....
Minimum	1.080	1.076	.....
Probable error	+ or — .018	+ or — .044	.....
CORN—			
Average (5 det.)	.418	(2 det.) .432	.....
Maximum	.430	.450	.....
Minimum	.410	.414	.....
Probable error	+ or — .004	+ or — .030	.....
PEAS—			
Average (5 det.)	.580	(1 det.) .627	.....
Maximum	.600	.....	.....
Minimum	.560	.....	.....
Probable error	+ or — .0017	.....	.....
BEANS—			
Average (5 det.)	.736	.....	.....
Maximum	.790	.....	.....
Minimum	.670	.....	.....
Probable error	+ or — .038	.....	.....
WHEAT—			
Average (16 det.)	.374	(13 det.) .342	.....
Maximum	.400	.405	.....
Minimum	.340	.302	.....
Probable error	+ or — .044	+ or — .076	.....
CASEIN—			
Average (4 det.)	.799	(1 det. .809	(1 det.) .809
Maximum	.805	.....	.....
Minimum	.793	.....	.....
Probable error	+ or — .0034	.....	.....
GLUTEN—			
Average (3 det.)	2.202	(1 det.) 2.165	(1 det.) 2.175
Maximum	2.235	.....	.....
Minimum	2.165	.....	.....
Probable error	+ or — .018	.....	.....

above named analyst obtained an average of 0.799% of sulfur trioxide by the bomb method as compared with 0.809% of sulfur trioxide obtained by the Haywood and Osborne methods. The results obtained by the Parr and Official methods for the determination of sulfur trioxide in linseed-meal, corn, peas, beans, and wheat are also recorded in Table I.

Results such as those noted in Table I clearly show that the bomb method can be successfully used without in any way sacrificing accuracy for speed.

Certain modifications have to be employed when analyzing for sulfur in soil that are considered unneccessary when analyzing for total sulfur in plant materials. The details of the Parr bomb method as adopted by us are as follows

SULFUR DETERMINATION IN PLANT MATERIALS

Charge. Some plant materials contain very small quantities of sulfur. In order to accurately determine the quantity of sulfur contained in materials bearing limited quantities of sulfur it is necessary to use the largest possible charge of the material that the bomb will carry and at the same time make the operation safe and successful. Experience has shown that in charging the bomb with plant materiials such as gluten, etc., it is unwise to explode more than 0.70 grams of the material. As a matter of convenience we use 0.687 grams of the material in each charge for the reason that the barium sulfate obtained from this quantity divided by 0.02 gives the per cent of sulfur trioxide contained in the sample.

Fusion Mixture. The fusion mixture used by us, with one exception, is identical with the one recommended by Parr. The exception is in the use of sodium nitrate, which we have substituted for potassium nitrate in order to avoid the known tendency of the potassium salts to form double salts with barium (12). The formula for the fusion mixture which we use is as follows:

Boric acid, finely powdered ....5 parts by weight
Sodium nitrate, finely powdered ......4 parts by weight
Magnesium metal, finely powdered ....1 part by weight

Sodium peroxide. The quantity of sodium peroxide required for a charge of 0.687 grams of material will vary be-

tween 12 to 16 grams. The exact amount of sodium peroxide required will depend upon the nature of the material to be analyzed. For gluten and similar nitrogenous substances we use approximately 16 grams of sodium peroxide. Working with starchy substances such as flour we find that 12 to 14 grams of sodium peroxide are ample.

Bomb. The electrodes in the Parr bomb apparatus, as purchased, are too long for the quantity of material that we use in each charge. The electrodes can be easily shortened. The electrode opposite the center unscrews readily, and is the only one that needs to be removed. The electrodes are shortened on the flattened ends where the fuse wire is attached. For our work the electrodes were shortened about three-eighths of an inch, flattened out and notches were filed into flattened ends to serve as holders for the fuse wire. Since the electrodes were shortened we have had no trouble on account of electrodes extending into the fused mass.

If obtainable we would prefer a bomb having the bottom cast in one piece with the shell, and not removable as it is now made.

SULFUR DETERMINATION IN SOIL

The small quantity of sulfur that is usually present in soil makes it necessary to charge the bomb with larger quantities of soil material than is required for the analysis of sulfur in plant materials. We use two grams of finely pulverized soil for each charge. A charge of two grams of soil requires one gram of the above mentioned fusion mixture. In addition to the fusion mixture one-half gram of sugar is added. The components, soil, fusion mixture, and sugar are placed in the shell and mixed. Subsequently ten to twelve grams of sodium peroxide is added and the whole contents of the shell are thoroughly mixed. The shell is properly closed, placed in the electric contact holder and both the shell and holder are submerged in a vessel of running water. Within the space of a few minutes the content of the bomb is exploded.

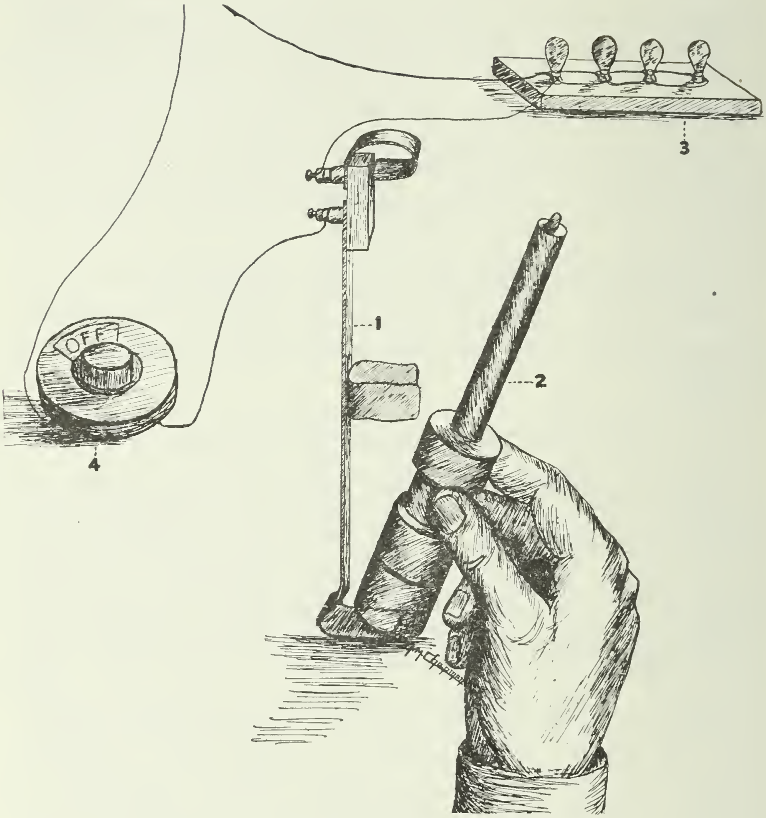

FIG. 1.—Electrical contact holder (1) designed to hold the bomb (2) while immersed in a jar of water. Four 16 candle power lamps (3) arranged in parallel series, and switch (4).

GENERAL

Removal of the fused mass. Several means for the removing of the fused mass have been devised in our laboratory. The most recently made device is one where the hot water passes thru glass tubing bent into U-shape into the shell containing the exploded mass. The orifice at the outlet end of the tube is made small on the inside of the tube there is contained a wire gauze and glass wool filter. With the use of the above mentioned contrivance we can reach up into the shell when the latter stands with its opening upturned downward over a beaker. The transfer of the material into the beaker is accomplished without loss. The bent glass tube also serves as a guide rod for the flow of the material and liquid. The small opening at the end of the tube reduces the amount of water used to a minimum.

Removal of silica. Contrary to the statements made by various authors it has been found necessary to remove the silica. It is impossible to obtain reliable results otherwise. Usually one evaporation of the liquid followed by one baking is sufficient. In making the sulfur determination in roots, soil, etc., it has been found necessary to repeat the evaporations, bakings, and filterings from two to three times in order to remove silica in quantities that might be sufficiently large to interfere with the actual sulfur occurring in the sample.

Precipitation of the sulfate. Much of our time has been employed in determining the best method for precipitating the sulfate. From the results of our experiments it has been found preferable to add ten cubic centimeters of ten per cent of cold barium chloride slowly and evenly on the surface of the cold liquid, which has first been neutralized with ammonium hydroxide and then slightly acidified with from five to six drops of concentrated hydrochloric acid. Upon standing twelve or more hours the mixture of sulfates and barium chloride is thoroly stirred, after which the mixture is allowed to stand at least until the barium sulfate has nearly if not entirely settled.

Preparation of the asbestos. Past experience has shown that it is difficult to obtain a good uniform grade of asbestos to serve as the filtering medium for gooch crucibles. The best asbestos that we have been able to obtain is the long

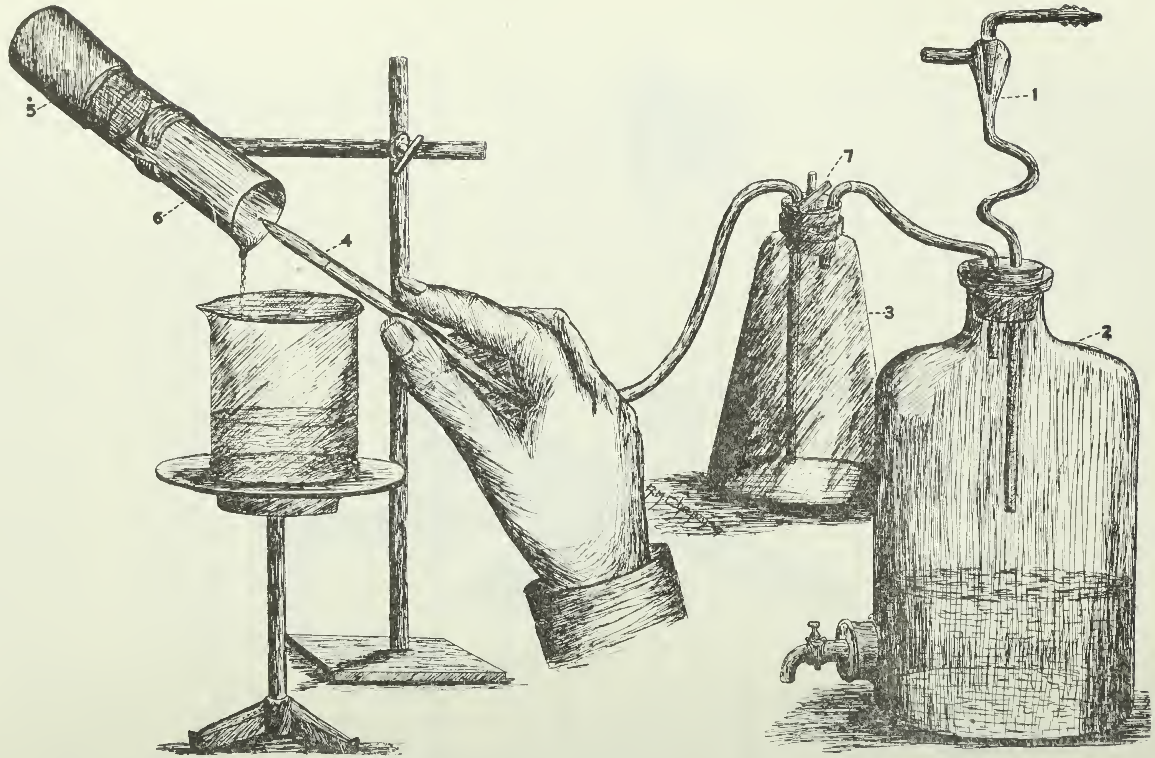

FIG. 2.—Apparatus designed for washing out the fused mass from bomb. Suction pump (1) is inserted into 4 quart aspirator bottle (2) and the two in combination form air pressure pump which forces hot water out of water bottle (3) through tube (4) and into bomb (5) which is inserted into glass tube (6). Tube (4) has been changed to one having a U shape so that the contents of bomb (5) can be washed directly into beaker from a vertical position.

fibered Italian asbestos. The asbestos should be thoroly digested in strong hydrochloric acid, washed, and ignited. The treated asbestos is then cut to suitable fineness and all of the finer particles washed thru a fifty mesh sieve. The remaining asbestos is then redigested in hydrochloric acid, thoroly washed and ignited. If the asbestos is properly prepared there should be no trouble in avoiding the loss of a part of the precipitate or any of the asbestos fiber in washing the filter.

Washing the barium sulfate precipitate. The barium sulfate precipitate should be thoroly washed with hot water. While in many cases three hundred cubic centimeters of water have been found ample to remove all traces of chloride, in other instances it has been found that as much as one thousand cubic centimeters had to be used to remove the last traces of chloride.

Phosphoric acid determination. The bomb method has been successfully used for making phosphoric acid determinations. The results obtained check with those obtained by other well known methods. The fact that it requires considerably more time to prepare the material for the determination of phosphorus by the bomb method than for determinations by other well known methods which are easier to manipulate makes the bomb method an undesirable one to follow for the determination of phosphoric acid.

CONCLUSIONS

The Parr calorimeter bomb can be successfully used for the estimation of total sulfur in plant residues and soil. There are certain precautions that must be closely adhered to. The material should be comminuted, the silica removed, and the barium sulfate thoroly washed free from chloride. The danger generally involved in the process of fusion is removed by following the bomb explosion method, and a larger number of fusions are thereby made possible in a comparatively short time.

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STATE COLLEGE OF WASHINGTON

AGRICULTURAL EXPERIMENT STATION

PULLMAN, WASHINGTON

DIVISION OF AGRICULTURE

Soil Physics

Factors Influencing the Water Requirements of Plants

By

C. C. THOM

and

H. F. HOLTZ

BULLETIN NO. 146

June, 1917

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FIGURES

Factors Influencing the Water Requirements of Plants

By

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and

H. F. Holtz, Assistant Soil Physicist

INTRODUCTION

A review of the literature on the subject of the water requirements of plants shows the results obtained so far to be somewhat conflicting. No two investigators have been able to agree on the exact water requirement of any particular plant. That this is so is undoubtedly due in a large degree to the difference in environment under which the investigations were carried on and to the widely varying methods of procedure followed in conducting them.

The necessity for making the greatest possible use of the limited annual precipitation in regions where dry farming is practiced and the the equally important problem of making the most economical use of water in irrigation demands that the factors which influence the water requirements of plants, and therefore crops, be more fully understood.

CHARACTER AND SCOPE OF WORK

The work reported in this bulletin was undertaken with a view to determining somewhat in detail the relative amounts of water used by different crops, the factors influencing the same, under existing climatic and soil conditions. The investigations of the relative water requirement of different crops was carried on in large tanks (Fig. 1) placed in the field, and also in field plots. The tank experiments were conducted in the seasons of 1911, 1912, and 1913, and those in the field plots in 1912, 1913, and 1914. Certain phases of

these were also carried on in the green-house under more perfectly controlled conditions. The dry, clear climate, with little rainfall during the growing season, gave ideal conditions under which to do work of this charatcer. The term "water requirement" used in this bulletin means the pounds of water used by the plant to produce a pound of dry matter.

RESULTS OF OTHER INVESTIGATORS

Directly and indirectly, there has been a large amount of literature dealing with the water requirement of plants, published in all parts of the world. Because of the great bulk of this mass of literature and the large number of factors that influence this requirement, only such literature will be cited as bears upon the work covered in this bulletin. The literature cited, however, is taken from the more important investigations carried on in different countries, climates, and conditions.

Kind of Crop

The relative water requirement depends upon two conditions. One, upon the many factors surrounding the plant, and the other the capacity of the plant to adapt itself to those factors. The soil and its treatment along with the climatic conditions are responsible for the different relative order of placing the water requirement of the ordinary farm crops. The following table gives the relative order of wheat, barley, and oats as found by different investigators, the water requirement of the following crops being given in increasing order.

Investigator— Crop	Seasonal Rainfall
Lawes, (15) Wheat, Barley	
Hellreigel, (9), Barley, Wheat, Oats	14.75
Briggs and Shantz, (3, 4, 5), Wheat, Barley, Oats	15.78 and 10.05
Von Seelhorst, (25), Wheat, Barley	14.75
Leather, (16), Oats, Barley, Wheat	3.37 and 3.85
Widtsoe, (26), Barley, Oats, Wheat	7.00
Thom and Holtz, Oats, Barley, Wheat	5.96 and 2.44

The foregoing table seems to indicate that summer rainfall is more suitable for wheat than it is for barley or oats.

Effect of Increasing the Plant Food Materials by Fertilization

Lawes (15) grew wheat, barley, and clover in pots using soil as a medium. These pots were divided into control, mineral salt fertilization without ammonium salts, and mineral salts with ammonium salts. The water requirement was 258, 236, and 209 respectively.

Hellriegel (9) conducted an experiment with quartz sand in pots to determine the effect of nitrogen and potassium on water requirement. His results show that barley gave an average water requirement of 440 and 315 with 4 and 20 milligrams of calcium nitrate and 525 and 330 with .4 and 3 milligrams potassium chloride, respectively.

King (13, 14) grew potatoes and corn in large galvanized cylinders containing soil. The water requirement for corn on control cylinder was 309 and on the manure 240. Potatoes were grown on control and potassium nitrate fertilized soil with a water requirement of 509 and 528 respectively.

Widtsoe (26) reduced the water requirement of corn from 908 to 464 by adding manure. Mineral salts also gave a decrease which was not equal in amount, but probably depended upon the balance of the soil solution.

Bouyoucos (1) found that wheat seedlings grown in a solution containing 4500 p. p. m. had a water requirement of 375 and increased to 463 when grown in a solution containing only 375 p. p. m. of total salts. From this concentration down to distilled water the water requirement again decreased to 429.

Leather (16, 17) grew corn and wheat in crocks containing manured and unmanured soil. Corn on manured and unmanured soil required 330 and 450 pounds of water per pound of dry matter, while wheat required 550 and 850 respectively. He also used mineral fertilizers as follows as control, N, N-P, N-P-K. The water requirement for wheat was 889, 918, 544, and 568 and for corn 466, 482, 302, and 334 respectively.

Stiles (24) grew barley seedlings in water cultures in concentrations from .85% to .0092% obtaining very slight decreases in total dry matter produced, while Brenchley (2) performed a similar experiment with concentrations from .3% to .015% obtaining a very marked reduction in growth as the concentration decreased. The difference between the

two ratios of shoots to roots obtained by these two investigators leads us to believe that the difference is due to culture solutions.

Harris (8) used control, complete fertilizer and high nitrogen fertilizer for growing wheat and found the water requirement to be 682, 583, and 572 respectively.

Kiesselbach (10) grew corn in soil classed as infertile. intermediate and fertile with and without manure. The water requirement without manure was 463, 384, and 327 and with manure 323, 308, and 298 respectively.

The results of past investigators point to the fact that concentration of solutions is a factor causing a variation in water requirement, and that within the limits of concentration in which plants will grow, the plants in the more concentrated soil solution will use the soil moisture more economically. Few exceptions have been found to this statement and these exceptions are probably due to factors which are more influential than concentration.

Effect of Soil Moisture

Hellriegel (9) conducted an experiment having a wide range of soil moisture and his results show that barley used water most economically at about 20% to 50% of the moisture holding capacity of the soil.

Fortier's (7) results show that about 22 inches of irrigation water added to soil gives the lowest water requirement for oats.

Widtsoe (26) grew four crops in 10%, 15% and 20% moisture, but only corn showed any preference to a high moisture content, the other crops fluctuated from year to year.

Leather's (16, 17) results show the water requirement from 10%, 15%, and 20% moisture content 542, 502, and 603 respectively.

Pfeiffer, Blanck, and Flugel (22) determined the water requirement of oats in 10%, 7% and varying from 10% to 4% solid soil moisture content to be 390, 354, and 300 respectively.

Harris (8) grew wheat seedlings in eight different moisture contents. In the 11%, 13%, and 37½% moisture con-

tents the water requirements were 731, 696, and 854 respectively.

Kiesselbach (10) obtained a water requirement of 293 317, and 343 in soils with low, medium, and high water content respectively.

Morgan (22) found the water requirement of oats to be 776, 869, and 815 in 17.6%, 29.0%, and 42.3% moisture contents respectively.

The experiments carried on in the field under irrigation by the different Western Experiment Stations show that the duty of water decreases with increased applications of water.

Results of previous investigators indicate that crops have a higher water requirement when the soil has either a high or low water content than when a medium content is maintained.

Effect of Summerfallowing

Widtsoe (26) found that two types of soil which had been bare three years gave an average water requirement for corn of 565 and on a cropped soil an average of 774.

Effect of Alkali

Bouyoucos (1) used sodium chloride and sodium sulphate in connection with a nutrient solution. Each salt was made up in six concentrations ranging from 93.5 to 4500 p. p. m. The concnetration of the nutrient solution used in connection with above salts was 75 p. p. m. in all cases. The water requirement for the control was 511 and for the 4500 p. p. m. concentration, of sodium chloride 326, and for sodium sulphate, 419.

Lyon and Bizzell (18) used sodium sulphate as a nonnutrient salt in six concentrations, ranging from 82 to 5000 p. p. m. Sixty-eight cubic centimeters of nutrient solution was added to each concentration. The water requirement was 690 for the control, and 332 for the 5000 p. p. m. concentration.

Effect of Previous Crop

Briggs and Shantz (3) found that the water requirement for alfalfa following Kharkov wheat was 945, following Turkey, 912, and following Bluestem, 473.

Effect of Ash Content

Kiesselbach (10) observed that the factors which affect the quantity of water transpired per unit of dry matter, similarly effect the quantity of water per unit of ash in the plants. He found that the ration of the water requirement in a humid and dry atmosphere was 100 : 59.5 based upon the dry matter, and 100 : 62 based upon the ash, respectively. The difference in the water requirement in the two years 1914 and 1913, was in the ratio of 100 : 73 based upon dry matter, and 100 : 78 based upon ash content, respectively.

Effect of Variety

Briggs and Shantz (3) determined the water requirement of different varieties of a number of plants. The following table shows the range of the water requirement of a number of varieties:

Crop—	No. of Varieties	Range in Water Requirements
Wheat	6	364-457
Oats	4	399-491
Barley	4	403-443
Corn	6	342-415
Millet	4	187-248

Effect of Other Factors

Briggs and Shantz (3) and Kiesselbach (10) observed that transpiration and evaporation from free water surfaces were similarly affected by wind temperature, humidity, and other climatic factors, consequently any climatic factor that causes an increase in evaporation is usually followed by a rise in water requirement.

KIND OF CROP AS A FACTOR IN THE WATER REQUIREMENTS OF PLANTS

In the spring of 1911 an experiment was begun to ascertain the amount of water required by various crops to produce a unit of dry matter under natural, and as nearly as possible, field conditions. For this purpose forty-four galvanized iron tanks, three feet deep and two feet in diameter,

were secured. These tanks were filled with a silt loam soil of the Experiment Station farm to within two inches of the top; the soil being placed in the tanks in the same relative position as found in the field. The soil was firmly tamped as

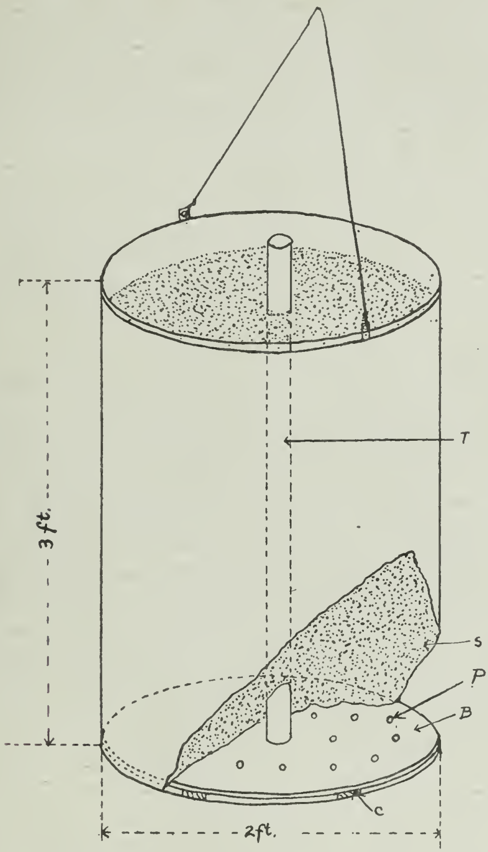

Fig. 1. Illustration of the device by means of which water was added to tanks. (T). Tube leading from top to bottom. (B). False bottam. (C). Cleats supporting false bottom. (S). Soil mass. (P). Perforations in false bottom.

the tank was being filled, so that on completion the column of soil in the tank was similar to a like column in the field. Each filled tank was then placed within a second tank, which had been sunk in the soil in such a manner that the top of the tank was in the same horizontal plane as the surface of

the soil surrounding it. The outside tank was of the same depth as the inside tank, but of two inches greater diameter. The space between the two tanks was filled with water, thus assuring that the thermal condition of the soil in the inner tank would be that of the field soil surrounding the outer tank. Before planting, sufficient water was added to the soil in the inner tank to make the total amount about sixty per cent of its capillary capacity. This percentage of water was maintained thruout the experiment. When the soil in the had reached a uniform moisture condition eighteen different crops were planted in duplicate tanks and interspersed among these were eight control tanks containing no crops. The experiment was conducted in the midst of a large oat field, the plants of which completely surrounded each and every tank.

The initial weighing was made on the day of planting, and twice weekly thruout the experiment. The weighings were made by raising the inner tank above the ground by means of pulleys and transferring it to a butches's scale that was fastened to a crane above. Sufficient water was added after each weighing to bring the weight of the tank up to the initial weight. The water was not added to the surface but to the bottom of the soil by means of a pipe which led from the top to a water chamber in the bottom of the tank.

When the plants appeared above the soil they were thinned so that there remained no more plants per unit surface than would be found under good field conditions. At the same time a two-inch layer of medium sand was added to all tanks, both control and cropped. This layer of sand proved a very efficient soil mulch. By comparing the loss from the sand covered tanks with others not so treated, it was found that the loss by evaporation was reduced by nearly sixty per cent.

On the day of harevsting both control and cropped tanks received their last weighing. In each case the difference between the initial weight and the last weight, plus the water added during the growing season, plus the rainfall during the same period, represented the water lost by each tank. By deducting the average amount of water lost from the control tanks from that lost from the cropped tanks, the amount of water used by each crop was ascertained.

The parts of the crops harvested for the determination

of the water requirements were as follows: The cereals and grasses were cut off just below and the legumes just above the root crowns. The tops, fruits and all starchy parts of the vegetables were used. No roots were taken in any case.

After removing the plants from the tanks the total products was thoroly air dried and the yield of grain, straw, roots, tubers or forage, as the case might be, was determined. The total product for each crop was then dried in an electric Friez oven at 105° C. until no further loss of moisture occurred.

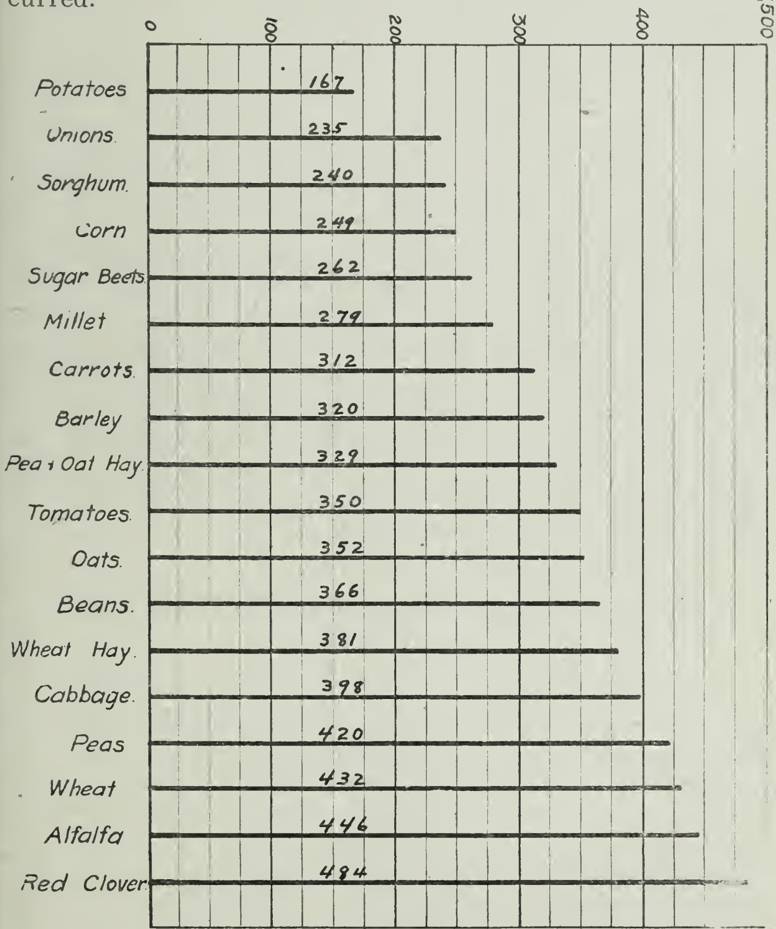

Fig. 2. Pounds of water required to produce a pound of dry matter. Crops grown in tanks. (See Fig. 1). 3 ft. deep; 2 ft. diameter. Seasons 1911, 1912, 1913.

The results shown in Fig. 2 have no exact value; the many factors which influence the water requirement of plants make it exceedingly difficult if not impossible to duplicate results from any particular plant. No two investigators have ever agreed on the exact amount of water required to produce a unit of dry matter in the same kind of plant, altho they quite generally agree on the relative amount when grown under similar conditions. The relative value, therefore, of these results is considerable in that they indicate those crops best suited to dry land agriculture. The table presents one notable exception in this respect, viz., that of wheat. This can in part be explained by climatic conditions as shown by results of previous investigators, (p. 6). When wheat is grown in a section having a high summer rainfall it uses the soil moisture more economically than barley or oats, but where the greater portion of the rainfall occurs in the winter the reverse is true. The success of wheat as a dry land crop is readily explained by its ability to produce mature and marketable gain despite great derth of available water supply. Yields of from 3 to 5 bushels of marketable wheat per acre are frequently reported from the drier sections (7 to 10 inches of rainfall). Rye is equal if not superior to wheat in this respect. No cereal crops other than wheat or rye possess this remarkable ability in such a marked degree. This ability to produce a small yield of good grain during seasons of limited rainfall constitutes one of the most essential factors of drought resistance.

WATER REQUIREMENTS OF CROPS UNDER FIELD CONDITIONS

It is always a question as to how nearly controlled experiments carried out in a small way, approach or approximate field conditions. The original plan of the water requirement investigations included the growing of some of the crops in field plots during the same seasons that these crops were grown in tanks. In the spring of 1911 a tract of land suitable for field tests could not be secured. A suitable tract was secured in the spring of 1912 and the field tests were begun. The tank investigations were for the seasons of 1911 1912 and 1913, while the field tests were for the seasons of 1912 1913 and 1914. The field plot were one-twelfth

of an acre in area. Each crop was sown on duplicate plots. For each pair of duplicate plots sown to crops there was one bare fallow or control plot. The control plots were for the purpose of determining the loss of soil moisture by evaporation. All control plots were kept well mulched during the growing season.

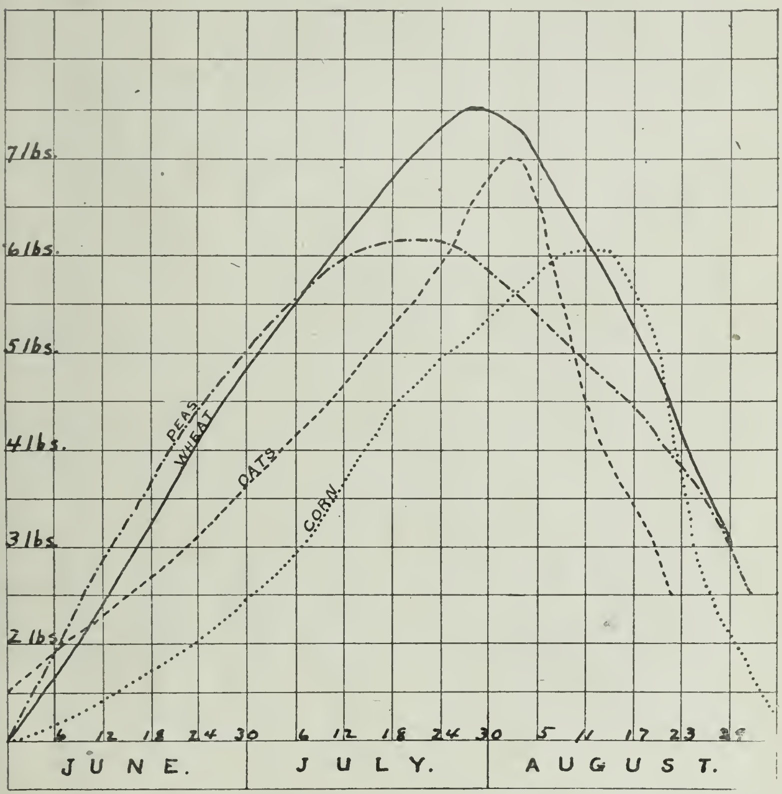

Fig. 3. Water used daily by wheat, barley, oats and peas, determined from bi-weekly weighings thruout the period of development. Average of 4 tanks. Area 3 1/7 sq. ft. per tank. Seasons 1911 and 1912.

Samples of soil for soil moisture determinations were taken in triplicate from each plot to a depth of ten feet, just as the plants appeared above the surface of the soil. In the same manner and to the same depth, moisture samples were taken on the day of harvest. Determinations were

made on the control plots on the same dates as on those plots for which they served as checks. The triplicate borings for moisture saamples were at points approximately one-fourth the length of the plot from each end, and in the middle.

No attempt was made to determine directly the total weight of dry matter produced on each field plot, but the total field weight of grain and straw produced was found in each case and ten pounds of the product from each plot was then dried to constant weight at 105° C. as in former determinations. Just after harvest the stubble from a representative square, 10 feet to the side, was taken from each plot and the total dry matter in the stubble ascertained. From the amounts thus determined the total dry matter produced on each plot was calculated.

FIELD TESTS SEASON OF 1912.
TABLE I.
WHEAT

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	23.19	8.85	14.34	11.47	1	22.50	20.64	1.86	1.49
2	21.38	9.92	11.46	10.54	2	21.91	19.71	2.20	2.02
3	20.69	9.11	11.58	11.34	3	20.35	18.91	1.44	1.41
4	21.20	8.75	12.45	12.70	4	21.22	20.63	.59	.60
5	23.16	10.75	12.41	13.02	5	23.73	22.18	1.55	1.63
6	24.17	14.55	9.82	10.40	6	24.65	21.59	3.06	3.24
7	23.93	15.32	8.61	9.13	7	22.86	22.20	.66	.70
8	23.90	17.92	5.98	6.35	8	20.85	20.77	.08	.08
					9	21.58	20.92	.66	.70
					10	21.43	20.63	.80	.85
Total loss per sq. ft. of surface				84.95	Total loss per sq. ft. of surface				12.72

TABLE II.

OATS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	23.53	9.18	14.35	11.49	1	24.90	21.44	3.46	2.77
2	21.44	10.28	11.16	10.27	2	23.15	21.58	1.57	1.44
3	20.84	10.28	10.56	10.33	3	21.81	21.29	.52	.51
4	20.49	10.47	10.02	10.23	4	22.86	20.41	2.45	2.50
5	21.57	11.58	9.99	10.50	5	22.86	20.86	2.00	2.10
6	21.74	15.30	6.44	6.82	6	23.16	21.22	1.94	2.06
7	22.17	18.71	3.46	3.67	7	23.15	21.89	1.26	1.34
8	22.01	19.53	2.48	2.63	8	22.86	22.10	.76	.86
9	22.39	20.67	1.72	1.82	9	23.08	23.15	+.07	+.07
10	22.31	20.75	1.56	1.65	10	25.00	23.91	1.09	1.16
Total loss per sq. ft. of surface				69.41	Total loss per sq. ft. of surface				14.67

TABLE III.

BARLEY

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Seeding	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	23.34	9.86	14.48	11.58	1	24.90	20.93	3.97	3.18
2	22.55	12.67	9.88	9.09	2	23.15	21.81	1.34	1.23
3	21.66	12.31	9.35	9.16	3	21.81	22.56	+.75	+.73
4	21.03	13.23	7.85	8.00	4	22.86	21.89	.97	.99
5	21.24	16.76	4.48	4.71	5	22.86	22.41	.45	.47
6	22.93	19.09	3.84	4.07	6	23.16	23.29	+.13	+.14
7	24.21	21.18	3.03	3.21	7	23.15	23.15	.00	.00
8	23.82	22.07	1.75	1.85	8	22.86	22.63	.23	.24
9	24.52	21.31	3.21	3.40	9	23.08	22.25	.83	.88
10	23.84	21.77	2.07	2.20	10	25.00	23.08	1.92	2.04
Total loss per sq. ft. of surface				57.27	Total loss per sq. ft. of surface				8.16

TABLE IV.
CORN

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	26.52	18.71	7.81	6.25	1	24.90	20.93	3.97	3.18
2	24.15	16.49	7.66	7.05	2	23.15	21.81	1.34	1.23
3	23.39	17.04	6.35	6.22	3	21.81	22.56	+.75	+.73
4	21.40	17.76	3.64	3.72	4	22.86	21.89	.97	.99
5	19.87	18.18	1.69	1.77	5	22.86	22.41	.45	.47
6	16.86	17.97	+1.11	+1.18	6	23.16	23.29	+.13	+.14
7	17.21	16.90	.31	.33	7	23.15	23.15	.00	.00
8	18.32	18.64	+.32	+.34	8	22.86	22.63	.23	.24
9	18.43	18.52	+.09	+.10	9	23.08	22.25	.83	.88
10	17.36	19.10	+1.74	+1.84	10	25.00	23.08	1.92	2.04
Total loss per sq. ft. of surface				21.88	Total loss per sq. ft. of surface				8.16

TABLE V.
PEAS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	25.01	9.84	15.17	12.13	1	25.00	23.46	1.54	1.23
2	27.27	11.06	16.21	14.90	2	23.75	23.01	.74	.68
3	22.00	11.64	10.36	10.14	3	21.96	21.73	.23	.23
4	21.57	17.23	4.34	4.43	4	22.48	21.74	.74	.75
5	22.26	20.38	1.88	1.97	5	21.97	20.86	1.11	1.17
6	23.84	23.12	.72	.76	6	21.70	21.59	.11	.17
7	24.77	22.01	2.76	2.93	7	22.62	23.38	+.76	+.80
8	22.95	22.85	.10	.11	8	22.26	23.11	+.85	+.90
9	23.38	22.59	.79	.84	9	23.23	23.41	+.18	+.19
10	22.19	21.77	.42	.45	10	23.84	23.02	.82	.87
Total loss per sq. ft. of surface				48.66	Total loss per sq. ft. of surface				3.21

TABLE VI.
BEANS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	26.19	18.08	8.11	6.50	1	25.78	21.29	4.49	3.58
2	23.99	15.64	8.35	7.68	2	24.22	20.11	4.11	3.78
3	21.75	17.12	4.63	4.54	3	22.10	18.14	3.96	3.88
4	20.57	17.85	2.72	2.78	4	20.92	18.12	2.80	2.86
5	20.68	17.48	3.20	3.36	5	20.49	17.94	2.55	2.68
6	19.76	17.76	2.00	2.12	6	19.20	17.61	1.59	1.69
7	19.28	18.33	.95	1.01	7	18.07	19.27	+1.20	+1.27
8	19.21	19.59	+.38	+.40	8	18.36	17.88	.48	.50
9	18.95	19.23	+.28	+.30	9	17.51	17.09	.42	.44
10	17.95	19.07	+1.12	+1.19	10	17.24	16.96	.28	.29
Total loss per sq. ft. of surface				26.10	Total loss per sq. ft. of surface				18.43

TABLE VII.
MILLET

CONTROL PLAT					CROPPED PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	26.99	18.42	8.57	6.86	1	26.99	22.10	4.89	3.91
2	24.68	13.38	11.30	10.40	2	25.39	21.36	4.03	3.70
3	22.62	13.38	9.24	9.10	3	23.08	21.00	2.08	2.04
4	20.58	16.16	4.42	4.51	4	21.90	22.01	+.11	+.11
5	24.24	16.75	7.49	7.86	5	20.93	21.44	+.51	+.54
6	23.63	18.15	5.48	5.81	6	23.61	23.31	.30	.32
7	22.02	18.77	3.25	3.45	7	23.46	21.80	1.66	1.76
8	20.71	19.27	1.44	1.53	8	22.47	21.37	1.10	1.17
9	20.33	18.70	1.63	1.73	9	21.53	21.15	.38	.40
10	20.41	18.56	1.85	1.96	10	21.48	22.70	+.22	+.23
Total loss per sq. ft. of surface				53.21	Total loss per sq. ft. of surface				12.42

TABLE VIII.

Sumary of Water Requirements of Crop Under Field Conditions for the Season of 1912.

Crop	Total Water Lost by Plot in Crop, Tons	Total Water Loss by Check Plat Tons	Total Water Transpired by Crop, Tons	Total Units Dry Matter produced on Plat	Pounds Water Transpired by Crop to Produce 1lb. dry matter
Wheat	154.1	23.1	131.0	670	391
Oats	126.0	26.6	99.4	630	316
Barley	104.0	14.8	89.2	525	340
Corn	39.7	14.8	24.9	264	189
Peas	88.4	5.8	82.6	394	419
Beans	47.4	33.5	13.9	112	248
Millet	96.6	22.6	74.0	471	314

FIELD TESTS SEASON OF 1913.

TABLE IX.

WHEAT

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	23.61	9.21	14.40	11.51	1	25.76	22.21	3.55	2.84
2	23.05	9.81	13.24	12.20	2	24.43	21.95	2.48	2.28
3	22.45	9.83	12.62	12.39	3	23.51	20.97	2.54	2.49
4	22.53	9.83	12.70	12.44	4	24.21	22.61	1.60	1.63
5	22.34	11.32	11.02	11.60	5	23.33	21.70	1.63	1.71
6	21.98	13.56	8.42	8.94	6	22.27	20.27	2.00	2.12
7	22.28	17.23	5.05	5.35	7	21.58	20.43	1.15	1.22
8	23.57	19.61	3.96	4.20	8	23.67	21.92	1.75	1.85
9	23.13	22.79	.34	.36	9	24.80	23.86	1.68	1.78
10	23.83	22.86	.97	1.03	10	23.17	21.86	1.31	1.39
Total loss per sq. ft. of surface				80.02	Total loss per sq. ft. of surface				19.31

TABLE X.
OATS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	21.73	8.23	13.50	10.80	1	23.46	20.97	2.49	1.99
2	22.22	9.83	12.39	11.39	2	21.51	20.93	.58	.53
3	21.39	9.34	12.05	11.80	3	20.83	19.62	1.21	1.19
4	21.00	9.61	11.39	11.60	4	19.94	20.16	+.22	+.22
5	20.95	11.76	9.17	9.64	5	20.02	19.73	.29	.30
6	20.69	16.69	4.04	4.29	6	23.31	21.31	2.00	2.12
7	21.82	19.28	2.54	2.70	7	23.36	21.91	1.45	1.54
8	23.24	21.47	1.77	1.88	8	23.88	22.05	1.83	1.94
9	22.66	20.96	1.70	1.80	9	22.88	21.79	1.09	1.16
10	22.62	21.26	1.36	1.44	10	22.62	21.80	.82	.87
Total loss per sq. ft. of surface				67.34	Total loss per sq. ft. of surface				11.42

TABLE XI.
BARLEY

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	21.50	10.30	11.20	8.96	1	23.46	20.97	2.49	1.99
2	22.54	11.32	11.32	10.41	2	21.51	20.93	.58	.53
3	22.03	11.93	10.10	9.90	3	20.83	19.62	1.21	1.19
4	22.08	13.09	8.99	9.16	4	19.94	20.16	+.22	+.22
5	21.65	16.21	5.44	5.71	5	20.02	19.73	.29	.30
6	22.31	18.81	3.50	3.71	6	23.31	21.31	2.00	2.12
7	23.63	21.41	2.22	2.38	7	23.36	21.91	1.45	1.54
8	22.71	21.75	.96	1.02	8	23.88	22.05	1.83	1.94
9	22.07	21.65	.42	.44	9	22.88	21.79	1.09	1.16
10	21.94	21.67	.27	.86	10	22.62	21.80	.82	.87
Total loss per sq. ft. of surface				52.55	Total loss per sq. ft. of surface				11.42

TABLE XII.
CORN

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	25.15	12.11	13.04	10.43	1	26.04	22.46	3.58	2.85
2	22.89	13.59	9.30	8.55	2	23.26	21.76	1.50	1.38
3	22.87	15.25	7.62	7.46	3	22.80	21.51	1.29	1.26
4	22.33	17.40	4.93	5.04	4	23.56	22.01	1.55	1.58
5	22.64	20.62	2.02	2.12	5	23.38	22.60	.78	.82
6	23.71	22.13	1.58	1.67	6	24.09	23.32	.77	.82
7	22.72	22.68	.04	.04	7	24.68	23.05	1.63	1.73
8	22.43	23.11	1.32	1.40	8	24.08	23.77	.31	.33
9	21.94	21.42	.52	.55	9	25.10	24.17	.93	.99
10	21.68	21.46	.22	.23	10	25.12	22.91	2.21	2.34
Total loss per sq. ft. of surface				37.49	Total loss per sq. ft. of surface				14.10

TABLE XIII.
PEAS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	21.91	9.85	12.06	9.65	1	22.86	20.15	2.71	2.17
2	22.66	10.46	12.20	11.21	2	22.02	22.49	+.47	+.43
3	21.92	10.25	11.67	11.41	3	21.54	21.40	.14	.14
4	21.73	15.40	6.33	6.45	4	22.05	21.19	.86	.88
5	22.49	20.23	2.26	2.37	5	23.66	23.37	.29	.31
6	24.03	21.29	2.74	2.91	6	22.86	21.57	1.29	1.37
7	22.90	21.31	1.59	1.69	7	22.48	21.76	.72	.77
8	22.20	21.40	.80	.85	8	22.41	21.84	.57	.60
9	22.38	21.57	.81	.86	9	22.58	22.51	.07	.07
10	22.19	21.59	.60	.64	10				
Total loss per sq. ft. of surface				48.04	Total loss per sq. ft. of surface				5.88

TABLE XIV.
BEANS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	26.49	11.49	15.00	12.00	1	25.43	19.39	6.04	4.84
2	22.70	13.16	9.10	8.91	2	22.42	21.61	1.26	1.16
3	22.14	16.62	5.52	5.40	3	22.42	21.51	.91	.89
4	21.68	19.03	2.65	2.70	4	21.83	21.23	.60	.61
5	22.28	20.51	1.77	1.86	5	21.67	21.55	.12	.13
6	22.51	21.72	.79	.84	6	22.80	22.16	.64	.68
7	22.71	21.79	.92	.97	7	23.85	22.42	1.43	1.51
8	22.57	21.80	.77	.82	8	23.29	22.72	.57	.60
9	22.93	22.15	.78	.83	9	24.91	22.29	2.62	2.78
10	22.66	21.41	1.25	1.32	10	25.10	23.81	1.59	1.69
Total loss per sq. ft. of surface				35.65	Total loss per sq. ft. of surface				14.89

TABLE XV.
MILLET

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	22.67	9.29	13.38	10.70	1	24.29	19.87	4.42	3.54
2	22.33	11.03	11.30	10.40	2	22.68	21.32	1.36	1.25
3	20.87	11.58	9.29	9.00	3	22.74	21.46	1.28	1.25
4	21.00	12.97	8.03	8.20	4	21.36	21.86	+.20	+.20
5	20.75	16.93	3.82	4.01	5	22.40	21.76	.64	.67
6	21.98	20.12	1.86	1.97	6	24.13	22.85	1.28	1.36
7	21.65	20.73	.92	.97	7	22.68	22.01	.67	.71
8	21.79	20.33	1.46	1.55	8	22.47	22.21	.26	.27
9	20.74	19.85	.89	.95	9	22.52	21.13	1.36	1.47
10	21.70	19.58	2.12	2.25	10	21.92	21.41	.51	.54
Total loss per sq. ft. of surface				50.00	Total loss per sq. ft. of surface				10.86

TABLE XVI.

Summary of Water Requirements of Crops Under Field Conditions for the Season 1913.

Crop	Total Water Lost by Plot in Crop, Tons	Total Water Loss by Check Plat Tons	Total Water Transpired by Crop, Tons	Total Pounds Dry Matter produced on Plat	Pounds Water Transpired by Crop to Produce 1lb. dry matter
Wheat	145.2	35.1	110.1	702	314
Oats	122.1	20.9	101.2	651	311
Barley	95.3	20.9	74.4	550	271
Corn	68.1	25.16	42.5	400	343
Peas	87.2	10.7	76.5	446	345
Beans	64.6	27.0	37.6	152	495
Millet	90.7	19.8	70.9	390	364

FIELD TESTS SEASON OF 1914.

TABLE XVII.
WHEAT

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	22.05	9.06	12.99	10.40	1	21.50	15.02	6.54	5.23
2	21.02	10.55	10.47	9.62	2	21.66	20.23	1.43	1.32
3	19.44	10.02	9.42	9.23	3	20.30	19.41	.89	.87
4	19.95	9.85	10.10	10.30	4	20.97	19.84	1.13	1.15
5	23.01	9.82	13.19	13.83	5	24.17	21.73	2.44	2.56
6	24.09	12.04	12.05	12.79	6	24.64	22.80	1.84	1.95
7	23.05	15.28	7.77	8.24	7	23.58	22.26	1.32	1.40
8	21.64	16.19	5.45	5.78	8	22.60	20.96	1.74	1.89
9	21.00	17.79	3.21	3.40	9	23.08	20.74	2.34	2.48
10	20.37	18.19	2.18	2.31	10	21.46	20.31	1.15	1.22
Total loss per sq. ft. of surface				85.90	Total loss per sq. ft. of surface				20.07

TABLE XVIII.
OATS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	21.84	10.35	11.49	9.19	1	22.40	15.86	6.54	5.22
2	21.96	11.03	10.93	10.07	2	22.51	20.99	1.52	1.40
3	21.29	11.21	10.08	9.86	3	21.71	20.63	1.08	1.06
4	21.07	12.09	8.98	9.16	4	21.56	21.44	.12	.12
5	21.11	15.31	5.80	6.10	5	21.91	22.10	+.19	+.20
6	22.58	17.90	4.68	4.96	6	21.82	22.62	.20	.21
7	22.40	19.47	2.93	3.10	7	22.61	22.02	.59	.63
8	22.79	20.52	2.27	2.40	8	22.66	22.50	.16	.17
9	21.99	21.12	.87	.92	9	23.21	22.30	.91	.96
10	22.79	21.57	1.22	1.29	10	25.00	22.47	2.53	2.68
Total loss per sq. ft. of surface				57.05	Total loss per sq. ft. of surface				12.25

TABLE XIX.
BARLEY

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	20.87	9.62	11.25	9.00	1	22.40	20.35	2.05	1.64
2	22.92	11.51	11.41	10.50	2	22.51	22.25	.26	.24
3	21.98	12.74	9.24	9.05	3	21.71	21.57	.14	.14
4	21.83	12.74	9.09	9.27	4	21.56	21.29	.27	.28
5	22.44	15.15	7.29	7.65	5	21.91	21.06	.85	.89
6	23.85	17.73	6.12	6.49	6	22.82	22.17	.65	.69
7	24.22	20.76	3.46	3.67	7	22.61	20.92	1.69	1.79
8	24.16	23.44	.72	.76	8	22.66	21.66	1.00	1.06
9	23.51	22.45	1.06	1.12	9	23.21	22.48	1.73	1.83
10	23.61	23.16	.45	.48	10	25.00	22.48	2.52	2.68
Total loss per sq. ft. of surface				57.99	Total loss per sq. ft. of surface				11.24

TABLE XX.
CORN

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	23.64	12.48	11.16	8.93	1	20.92	16.41	4.51	3.61
2	23.58	11.71	11.87	10.90	2	21.07	20.77	.30	.28
3	21.32	17.95	3.37	3.30	3	20.05	19.48	.57	.56
4	20.17	12.77	7.40	7.55	4	19.90	19.47	.43	.44
5	18.30	13.92	4.38	4.60	5	19.78	19.26	.52	.55
Total loss per sq. ft. of surface				35.28	Total loss per sq. ft. of surface				5.44

TABLE XXI.
PEAS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	22.09	8.43	13.66	10.91	1	24.00	23.34	3.66	2.83
2	23.52	10.11	13.41	12.33	2	24.00	19.11	4.89	4.50
3	21.33	12.74	8.59	8.42	3	22.32	21.80	.52	.51
4	22.03	16.58	5.45	5.56	4	23.08	21.22	1.86	1.90
5	21.92	18.80	3.12	3.28	5	22.17	21.88	.29	.30
6	22.70	20.35	2.35	2.49	6	21.96	21.88	.08	.08
7	21.97	21.13	.84	.89	7	24.07	20.85	3.22	3.42
8	21.96	20.82	1.14	1.21	8	23.53	22.34	1.19	1.26
9	22.39	21.43	.96	1.02	9	25.39	24.57	.82	.87
10	21.29	21.21	.08	.08	10	24.94	23.46	1.48	1.57
Total loss per sq. ft. of surface				46.19	Total loss per sq. ft. of surface				17.24

TABLE XXII.

BEANS

CROPPED PLAT					CONTROL PLAT				
Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.	Depth	% Moisture in Soil at Seeding	% Moisture in Soil at Harvest	% Moisture Lost	Loss of moisture pounds per cu. ft.
1	22.03	9.84	12.19	9.74	1	20.92	16.41	4.51	3.61
2	21.63	11.90	9.73	8.95	2	21.07	20.77	.30	.28
3	20.56	13.12	7.44	7.28	3	20.05	19.48	.57	.56
4	19.81	14.99	4.82	4.92	4	19.90	19.47	.43	.44
5	19.06	16.83	2.23	2.34	5	19.78	19.26	.52	.55
Total loss per sq. ft. of surface				33.23	Total loss per sq. ft. of surface				5.44

TABLE XXIII.

Summary of Water Requirements of Crops Under Field Conditions for the Season 1914.

Crop	Total Water Lost by Plot in Crop. Tons	Total Water Loss by Check Plat Tons	Total Water Transpired by Crop, Tons	Total Units Dry Matter produced on Plat	Pounds Water Transpired by Crop to Produce 1lb. dry matter
Wheat	155.9	36.4	119.5	569	420
Oats	103.8	22.2	81.6	525	311
Barley	105.1	20.4	84.7	466	363
Corn	64.1	9.9	54.2	371	292
Peas	83.9	31.3	52.6	268	393
Beans	58.5	9.9	48.6	137	710

TABLE XXIV.

Summary of Water Requirements of Crops Under Field Conditions for the Seasons of 1912, 1913, and 1914.

Pounds of Water per Pound of Dry Matter

Crop	1912	1913	1914	Average
Wheat	391	314	420	375
Oats	316	311	311	313
Barley	340	271	363	325
Corn	189	212	292	231
Peas	419	343	393	385
Beans	248	495	710	484
Millet	314	364	...	339
Average	328	302	296	...

Results for millet not included.

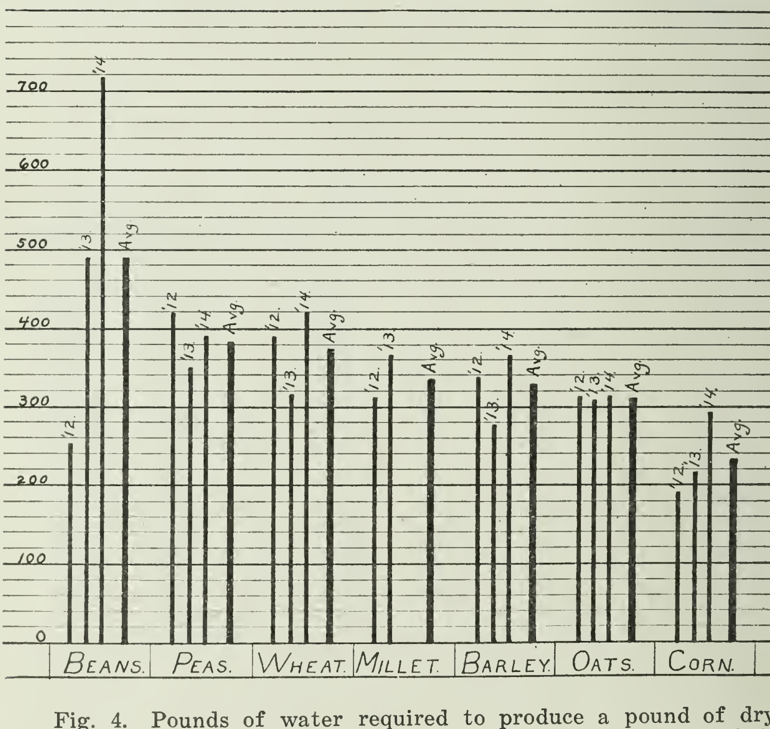

Fig. 4. Pounds of water required to produce a pound of dry matter under field conditions for the seasons 1912, 1913 and 1914.

Table XXV.

Inches of Rainfall During the Growing Season on Duty of Water Plats 1912, 1913, and 1914.

Crop	1912	1913	1914	Average
Wheat	5.02	3.06	1.71	3.30
Oats	5.02	3.06	1.71	3.30
Barley	5.02	3.06	1.71	3.30
Corn	6.57	2.09	.79	3.15
Peas	5.02	3.06	1.71	3.30
Beans	6.57	2.09	.79	3.15
Millet	6.57	.67	.11	2.45

TABLE XXVI.

Transpiration Loss from Cropped Plats.

Pounds per Square Foot of Soil Surface.

Crop	1912	1913	1914	Average	Acre Inches
Wheat	72.23	60.71	65.83	66.25	12.74
Oats	54.74	55.92	44.80	51.82	9.97
Barley	49.11	41.13	46.75	45.66	8.79
Corn	13.72	23.39	29.84	22.32	4.30
Peas	45.45	42.16	28.95	38.85	7.47
Beans	7.67	20.76	27.79	18.71	3.60
Millet	40.79	39.14		39.96	7.68

TABLE XXVII.

Evaporation Loss from Control Plats.

Pounds per Square Foot of Soil Surface.

Control for	1912	1913	1914	Average	Acre Inches
Wheat	12.72	19.31	20.07	17.47	3.36
Oats	14.67	11.42	12.25	12.78	2.46
Barley	8.16	11.42	11.24	10.28	1.98
Corn	8.16	14.10	5.44	9.57	1.84
Peas	3.21	5.88	17.24	8.74	1.70
Beans	18.43	14.89	5.44	12.91	2.48
Millet	12.42	10.86		11.69	2.25

TABLE XXVIII.

Yield per Acre on Field Plats.

Crop	1912 Grain bu.	1912 Straw tons	1913 Grain bu.	1913 Straw tons	1914 Grain bu.	1914 Straw tons	Average Grain bu.	Average Straw tons	Ratio grain Grain to Straw
Wheat ..	54.2	2.28	42.3	1.80	31.9	1.49	44.2	1.86	1:1.45
Oats	100.2	1.85	76.6	2.10	78.1	1.22	85.0	1.72	1:1.27
Barley ..	56.5	1.68	41.1	1.69	47.5	1.55	48.4	1.64	1:1.50
Corn	29.1	3.34	31.8	1.21	39.4	1.09	33.4	1.88	1:1.61
Peas	36.4	1.44	31.1	1.41	26.9	.97	31.5	1.27	1:1.34
Beans ...	10.9	.51	8.5	.50		.57	9.7	.51	1:1.75
Millet		3.60		1.90				2.75	

TABLE XXIX.

Water Requirements Under Field Conditions.

Average of Three Years.

Crop	Yield Average 3 Yrs. Grain bu.	Yield Average 3 Yrs. Straw tons	Ratio of Grain to Straw	Water Loss Acre Inches Transpiration	Water Loss Acre Inches Evaporation	Water Loss Acre Inches Rainfall	Water Loss Acre Inches Total
Wheat	44.2	1.86	1:1.45	12.74	3.36	3.30	19.40
Oats	85.0	1.72	1:1.27	9.97	2.46	3.30	15.73
Barley	48.4	1.64	1:1.50	8.79	1.98	3.30	14.07
Corn	33.4	1.88	1:1.61	4.30	1.84	3.15	9.29
Peas	31.5	1.27	1:1.34	7.47	1.80	3.30	12.57
Beans	9.7	.51	1:1.75	3.60	2.48	3.15	9.23
Millet		2.75		7.68	2.25	2.45	12.38

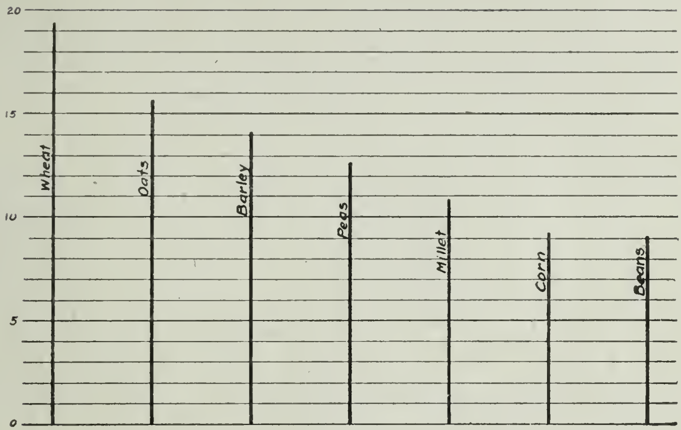

Fig. 5. Water requirements of crops, under field conditions, average of the seasons of 1912, 1913, and 1914, expressed in acre inches.

TABLE XXX.

Inches of Rainfall Necessary to Produce Equal Amounts of Dry Matter per Acre, Calculated from the Water Requirements, Table XXV.

Crop	Inches Rainfall
Wheat	20.00
Oats	16.70
Barley	17.33
Corn	12.32
Peas	20.53
Beans	25.83
Millet	17.92

Tables II.-XXX. give the data for the water requirements of the field tests for the years 1912, 1913, and 1914. The column showing "per cent mositure lost" is the difference between the initial and fall per cent of moisture. The pounds of water per square foot was determined from the actual weights of a cubic foot of soil, at the different depths.

The following table gives the weights of a cubic foot of moisture free soil from 1 to 10 feet in depth:

Depth	Weight	Depth	Weight
1	80 pounds	6	105 pounds
2	92 pounds	7	105 pounds
3	98 pounds	8	105 pounds
4	102 pounds	9	105 pounds
5	105 pounds	10	105 pounds

In each year one control plot served as check against two crops. In 1912 for barley and corn, in 1913 for oats and barley, and in 1914 for corn and beans.

The control plot for peas in 1912 lost only 3.21 pounds of water per square foot, which is low when compared to other plots. This is attributed to the particular location and high seasonal rainfall (Table XXV.). The plot was located in a slight depression at the beginning of a natural drainage slope. The high seasonal rainfall caused a slight underground movement of the soil moisture toward this depression, consequently the evaporation loss was lower than other plots not so situated. The difference in evaporation from the different control plots are due to a number of causes, such as soil differences, impossibility of maintaining identical mulch conditions, differences in location in reference to slope, exposure and shelter due to surrounding crops, etc. Because of these conditions it was necessary to have a control plot adjacent each cropped plot to check upon the evaporation.

The difference in the amount of rainfall upon the different crops presented in Table XXV. depend upon the time and length of the growing seasons.

While the results vary mor e or less from year to year, the relative water requirement remains approximately the same with the exception of the results for the bean crop, which shows a wide variation from year to year. The cli-

mate of this section is not suitable to the production of beans, as will be noted from the yields presented in Table XXIX. Consequently the average of results for beans as presented in Table XXIV. is of little value. The results for beans were included here to emphasize the fact that any factor, whether climatic or otherwise that causes an unsuitable or abnormal condition for any crop will almost invariably increase its water requirement. The season of 1912 was an average year for beans, the season of 1913 was below average, and the season of 1914 entirely unsuitable. The seasonal effects are remarkably apparent in the water requirement of beans for each of these seasons. Omitting the results for beans the average water requirement for all crops for 1912 is 328; in 1913, 302, and in 1914, 296. These results are remarkably close, considering the entire lack of control over field conditions.

TABLE XXXI.

Water Requirements of Crops. Tanks vs. Field

Crop	TANKS		FIELD		Ratio of Tank to Field Experiments Field 100%
	No. of Tests	Pounds of Water Transpired per lb. of Dry Matter Produced	No. of Tests	Pounds of Water Transpired per lb. of Dry Matter Produced	
Wheat	28	361	6	375	96.26
Corn	6	249	6	231	107.79
Oats	6	345	6	313	110.22
Barley	6	320	6	325	98.46
Peas	4	420	6	385	109.09
Beans	4	444	6	484	91.73
Millet	4	279	2	339	82.30

In Table XXXI. is presented a comparison of the water requirements of plants grown in tanks with the water requirements of the same plants grown on field plats. With the exception of beans and millet the results are quite uniform. Beans and millet are not able to adapt themselves to the climatic conditions of this section and this fact undoubtedly affected adversely the field trials. These crops were a complete failure during the extremely dry season of 1914.

The results for other crops are sufficiently close to warrant the statement that tank experiments, when properly conducted, will give results comparable with results obtained from field trials. The most significant fact, however, is that the relative water requirements for different crops are the same in each case. Those crops which show a low water requirement when grown in tanks again show a low water requirement in the field, and those crops with a high water requirement in tanks are also highest in the field.

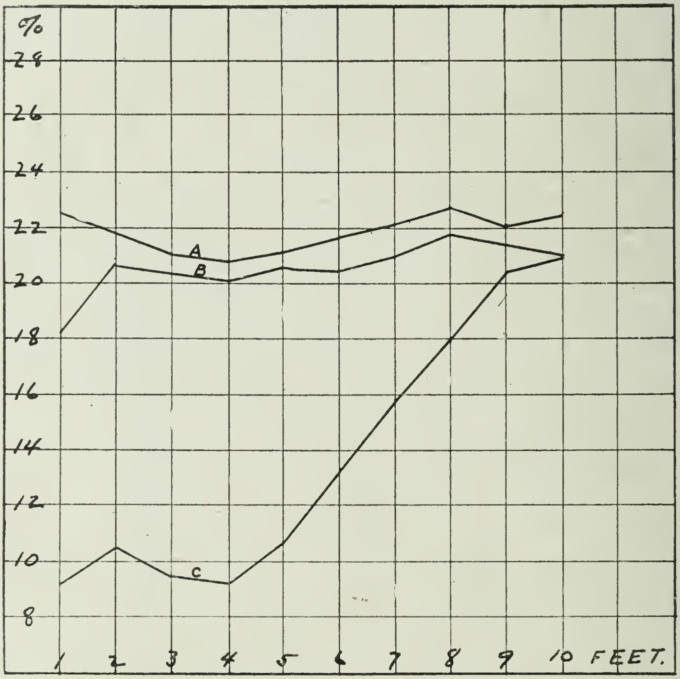

Fig. 6. Field plats average of the seasons 1912, 1913 and 1914. (A). Per cent of moisture in each foot of soil at seeding time; cropped plat. (B). Per cent of moisture in each foot of soil at harvest time; check plat. (C). Per cent of moisture in each foot of soil at harvest time; cropped plat.

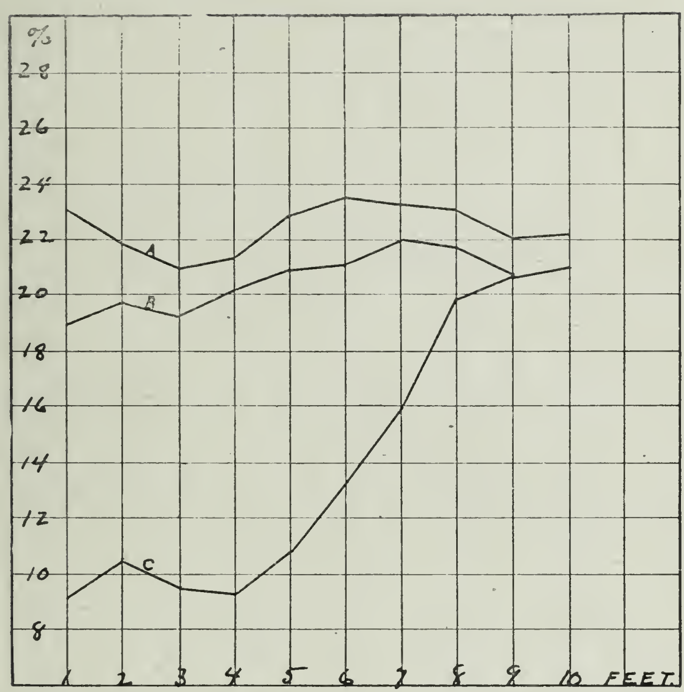

Fig. 7. Oats. Field plats average of the seasons 1912, 1913 and 1914. (A). Per cent of moistue in each foot of soil at seeding time; cropped plat. (B). Per cent of moisture in each foot of soil at harvest time; check plat. (C). Per cent of moisture in each foot of soil at harvest time; cropped plat.

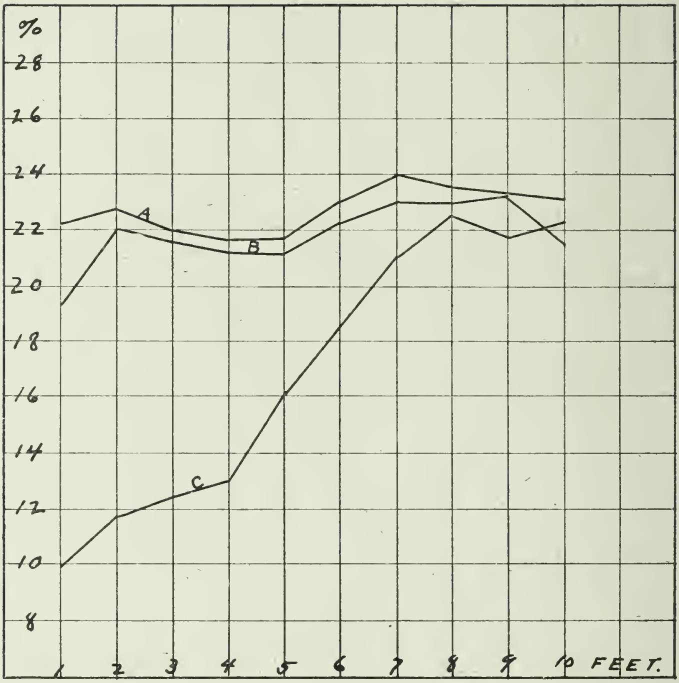

Fig. 8. Barley. Field plats average of the seasons 1912, 1913 and 1914. (A). Per cent of moisture in each foot of soil at seeding time; cropped plat. (B). Per cent of moisture in each foot of soil at harvest time; check plat. (C). Per cent of moisture in each foot of soil at harvest time; cropped plat.

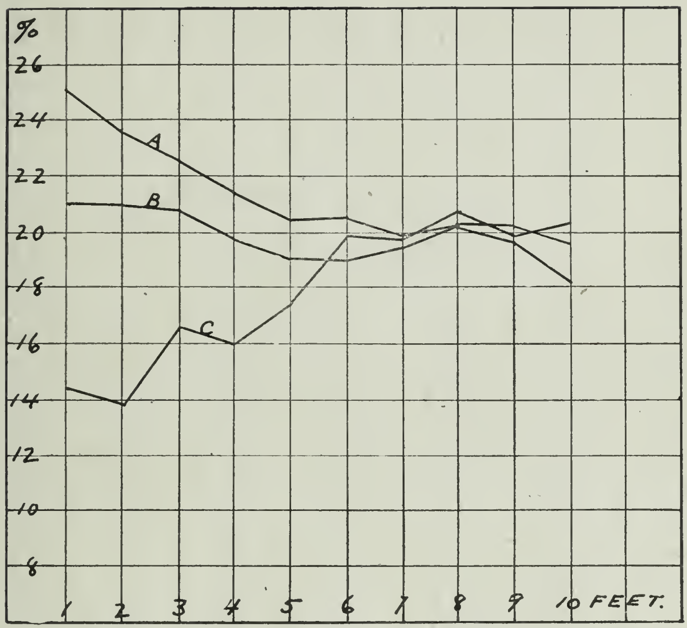

Fig. 9. Corn. Field plats average of the seasons 1912, 1913 and 1914. (A). Per cent of moisture in each foot of soil at seeding time; cropped plat. (B). Per cent of moisture in each foot of soil at harvest time; check plat. (C). Per cent of moisture in each foot of soil at harvest time; cropped plat.

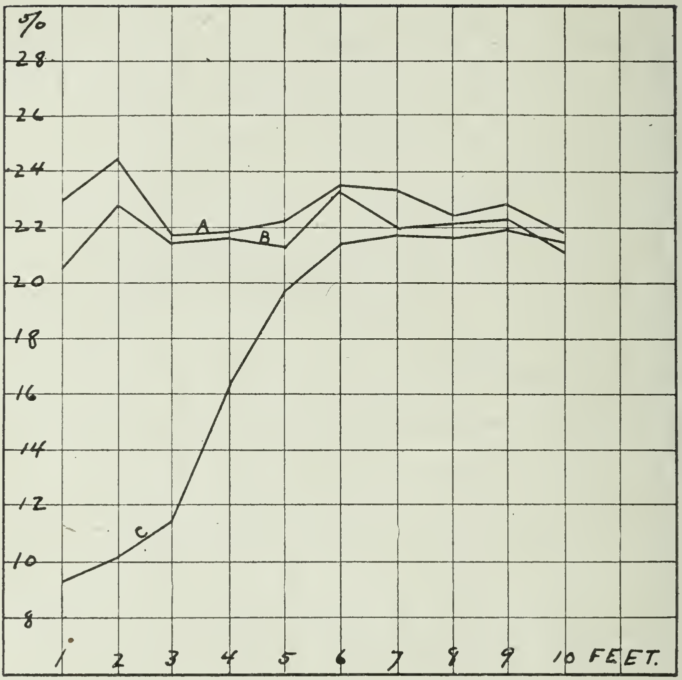

Fig. 10. Peas. Field plats average of the seasons 1912, 1913 and 1914. (A). Per cent of moisture in each foot of soil at seeding time; cropped plat. (B). Per cent of moisture in each foot of soil at harvest time; check plat. (C). Per cent of moisture in each foot of soil at harvest time; cropped plat.

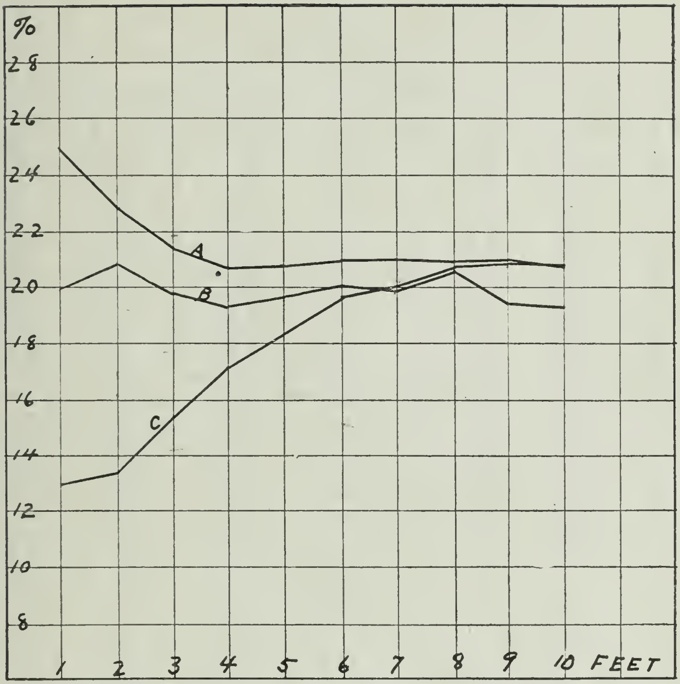

Fig. 11. Beans. Field plats average of the seasons 1912, 1913 and 1914. (A). Per cent of moisture in each foot of soil at seeding time; cropped plat. (B). Per cent of moisture in each foot of soil at harvest time; check plat. (C). Per cent of moisture in each foot of soil at harvest time; cropped plat.

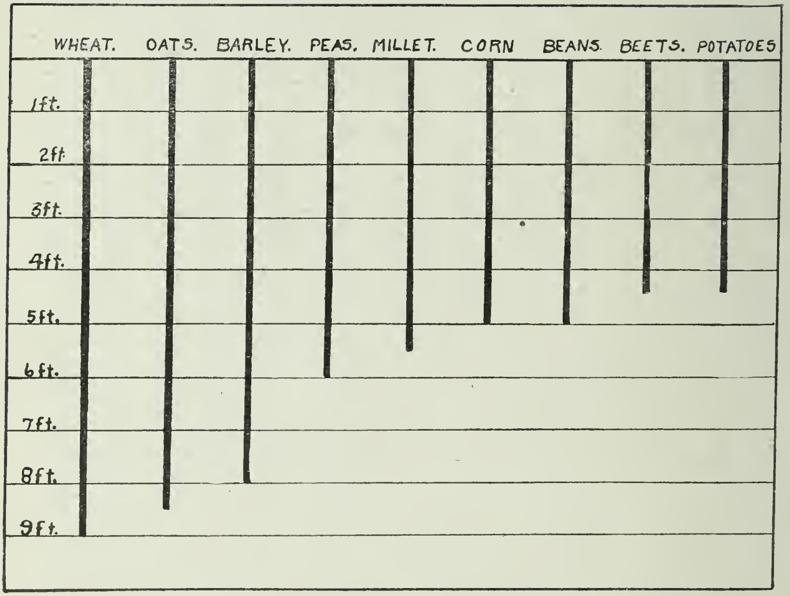

Fig. 12. Soil depth to which the different field crops take moisture. Average for the seasons of 1912, 1913 and 1914. A very good indication of the relative root development of these crops.

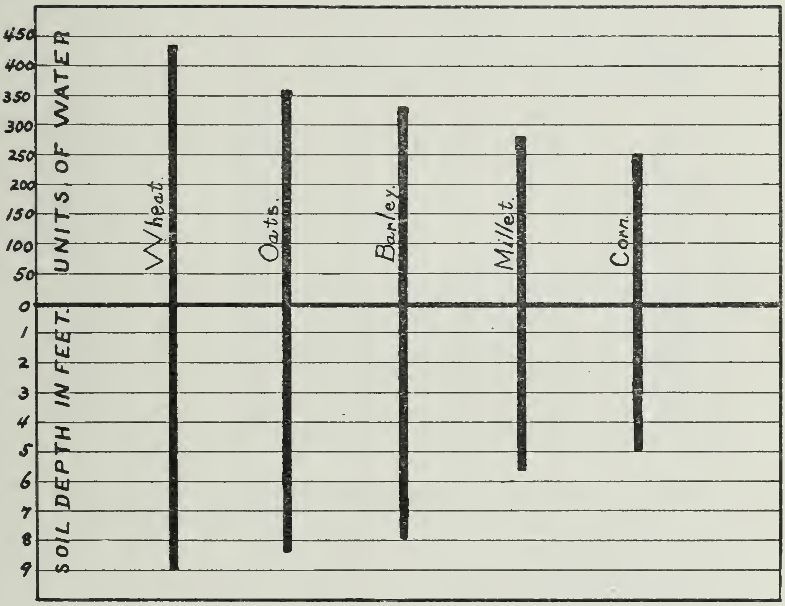

Fig. 13. Showing the relation of water requirements to root development. Above zero line, pounds of water required to produce a pound of dry matter; below zero line, depth to which plants took moisture.

PER CENT OF ASH IN PLANTS AS A FACTOR INFLUENCING THE WATER REQUIREMENTS.

From the crops grown in tanks six were chosen and ashed to determined if the limited soil volume of the tanks affected the composition of these plants as compared with similar crops grown in the field. Those chosen included two cultivated crops, corn and sorghum, two drilled crops, oats and barley, and two legumes, peas and red clover.

TABLE XXXII.

Per cent of Ash in Plants as a Factor Influencing the Water Requirement.

Kind of Crop	Per cent of Ash in Dry Matter of Mature Plants	Pounds of Water Transpired per Pound of Dry Matter Produced
Sorghum	1.4	230
Corn	2.5	249
Barley	4.3	320
Oats	4.7	345
Peas	7.4	420
Red clover	8.4	484

The ash content of the plants grown in the tanks was found to be practically the same as that for the same crops grown in similar soil in the open field. When the results were all compiled, however, it was observed that those plants with a relatively low ash content were also relatively low in water requirements.

Table XXXII. and Fig. 14 show that while the water requirements of these plants is not in direct ratio to their respective ash contents the relation is so close as to indicate that the relative ash content of any plant grown under normal agricultural conditions is a splendid index of its relative water requirement. It is quite unlikely, however, that the same relation of ash content to water requirement exisits in plants that have adapted themselves to a special environment, such as those that thrive in extremely arid conditions, or those adapted to highly alkaline soils.

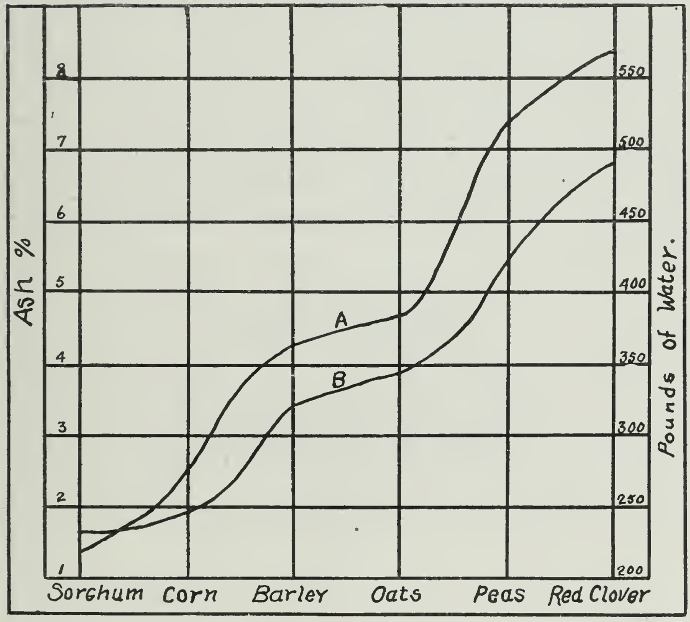

Fig. 14. Per cent of ash in plants as a factor infuencing the water requirement. (A). Per cent ash. (B). Pounds of water per pound of dry matter.

THE CONCENTRATION OF THE NUTRIENT SOIL SOLUTION AS A FACTOR AFFECTING THE WATER REQUIREMENTS OF PLANTS.

The fact that plants with a high ash content have a relatively higher water requirement than those wit a lower ash content suggested that the concentration of the soil solution in available plant food materials possibly might have a direct effect on the water requirement of any given plant. This theory was further suggested by the knowledge that the ash content of plants is fairly constant. With these considerations before us it seemed reasonable to believe that the more concentrated the soil solution is in the elements of plant nutrition the smaller will be the amount of the soil solution necessary to furnish desired amounts of these elements to the plant, provided the solution is not so strong in these elements as to be injurious to proper growth and development.

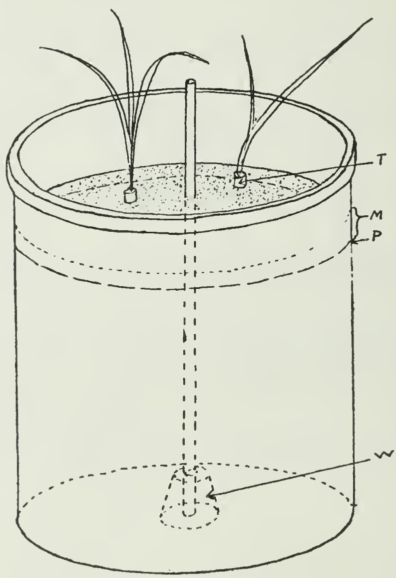

Fig. 15. Illustration of jar in which culture solution work was done. (T). Paraffined paper tube which was put around the young plant when melted paraffin was poured over the surface of the same. (P). Layer of paraffine. (M). One inch sand mulch. (W). Water chamber.

To prove the correctness of this theory a pure quartz sand was obtained analyzing 99.89% SiO_2—the impurity being .12% of iron and alumina. This soil medium was placed in two-gallon earthenware crocks. In each crock was fitted a one-quarter inch glass tube tube leading from the surface of the soil and terminating in a water chamber at the bottom of the crock (see Fig. 15). Water was thus added to the bottom of the soil in all instances. The crocks were filled to within one inch of the top. Sufficient culture solution was then added to each crock to bring the water content of the sand to 65% of its capillary capacity. The crocks were then planted with germinated seed, the plumule of which had reached a length of approximately three-fourths of an inch. Four seeds were placed in each plot in such a manner that the tip of plumule just showed on the soil surface. Around each projecting plumule was placed a paraffined paper tube. The crock was then sealed over with a heavy coat of paraffin to prevent any loss of moisture by evaporation. On top of the paraffin layer was an inch layer of dry quartz sand to serve as an additional protection against evaporation. The crocks were placed in an out-door shelter in such a manner that the tops of the crocks were level with the soil surface. The shelter consisted of a frame structure seven feet high with a glass roof and chicken wire sides. This structure prevented any rain from reaching the crocks, but in all other respects the climatic conditions were similar to those outside.

The crocks were arranged in sets of three and each set supplied with a different concentration of the culture solution.

The proportion of the different salts in the culture solution used in this experiment closely approximated Detmer's nutrient solution. The following table gives the proportions of the different salts used:

Calcium Nitrate	4 parts
Sodium Chloride	1 parts
Magnesium Sulphate	1 parts
Di-potassium Phosphate	1 parts
Ferric Chloride	Trace

Various concentrations of solutions were made from the above salts, but the relative proportions remained the same in each. The different concentrations were based upon a

water extract* from a fertile soil of this section. This concentration was found to be .083% which was taken as the optimum required for proper growth and development. The first experiment was conducted with six solutions of different concentrations, four of which contained less than .083% of total salts while two exceeded this amount. Tables XXXIII. and XXXIV. present the results of the first trial. Good results were obtained with all but the .004% solution. This strength was too weak to properly nourish the growing plants. Tables XXXIII. and XXXIV. and Fig. 16 clearly show that the water requirement decreases inversely with the concentration of the culture solution.

The following season the culture solutions were not diluted beyond .0125% of total salts nor made stronger than .2%. The results from this second trial proved more satisfactory than those of the first or preliminary one. This is shown in Table XXXVI. The more dilute solutions, .025% and .060%, were too weak for good growth. The yeild of dry matter increased from 5.8126 grams of dry matter for the .0125% solution to 80.2668 grams for the .1% solution. The .2% solution proved too strong for best development. The plants grown in this solution were of average height, ripened at the same time as the other plants, produced good plump seed, and seemed normal in every way except in that the plants did not stool as did the plants in the .1% solution. The yield of total dry matter from the .2% solution was but 38.9% of that from the .1% solution. Subsequent work has shown that when the culture solution contains more than .1% of soluble nutrient salts the solution is too strong for proper development of most plants.

The results given in Tables XXXV. and XXXVI. corroborating as they do the results of the previous seasons, given in Tables XXXIII. and XXXIV., emphasizes the importance of maintaining the soil fertility where the soil moisture is limited.

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*This extract was obtained by putting 500 cc. of distilled water upon 100 grams air dry soil. This mixture was occasionally stirred and filtered, after standing 24 hours, thru a porus clay cup. This filtrate was evaporated to dryness on a water bath, and then dried in a Friez electric oven at 105° C. for 24 hours and total soluble salts determined gravimetrically.

TABLE XXXIII.

Influence of Concentration of Nutrient Solution on the Water Requirements of Matured Wheat Plants Grown in Pure Quartz Soil.

Strength of Soil Soluion in per cent	Toal Grams of Dry Matter Produced; Stems and leaves only	Total Grams of Water Transpired	Grams of Water Transpired per Gram of Dry Matter Produced
.004	1.097	1296	1182
.01	2.143	1788	834
.02	3.398	2621	772
.04	6.728	3989	593
.1	13.227	6465	489
.2	21.190	9905	468

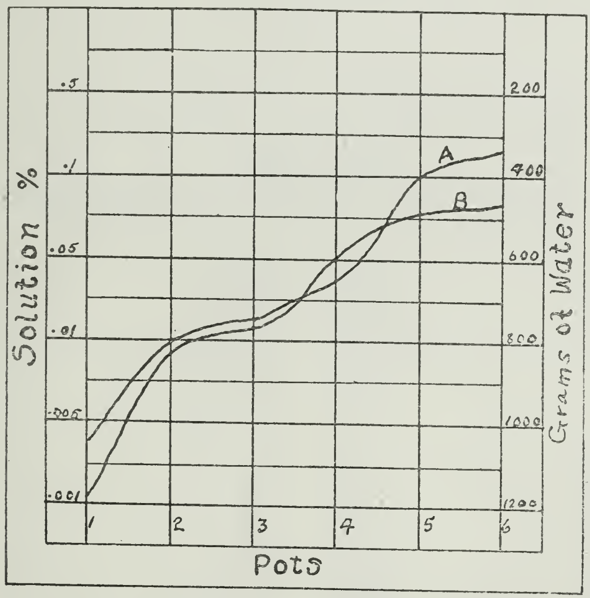

Fig. 16. Showing the relation existing between the concentration of the nutrient solution and the grams of water required to produce a gram of dry matter in wheat. (Taken from Table XXXIII.) (A). Solution per cent. (B). Grams water per gram of dry matter.

TABLE XXXIV

Influence of the Concentration of Nutrient Solution on the Water Requirements of Matured Oat Plants Grown in Pure Quartz Soil.

Strength of Nutrient Solution in per cent	Total Grams of Dry Matter Produced Whole Plant	Total Grams of Water Transpired	Grams of Water Transpired per Gram of Dry Matter Produced
.004	1.215	915	752
.01	2.664	1588	596
.02	7.357	3033	412
.04	11.666	4902	420
.1	24.074	9420	392
.2	29.616	11462	387

TABLE XXXV.

Influence of Strength of Nutrient Solution on Water Requirement of the Wheat Plant Grown in Pure Quartz Soil.

Strength of Solution	Grams of Water Transpired per Gram of Dry Matter Produced; Whole Plant	Grams of Water Transpired per Gram of Dry Matter Produced; Stem and Leaves Only	Grams of Water Transpired per Gram of Ash Produced; Whole Plant
.0125	605	1074	7485
.0166	503	848	7438
.0333	408	700	4950
.0500	380	492	4970
.0666	324	446	3630
.1000	262	316	3028
.2000	236	286	1777

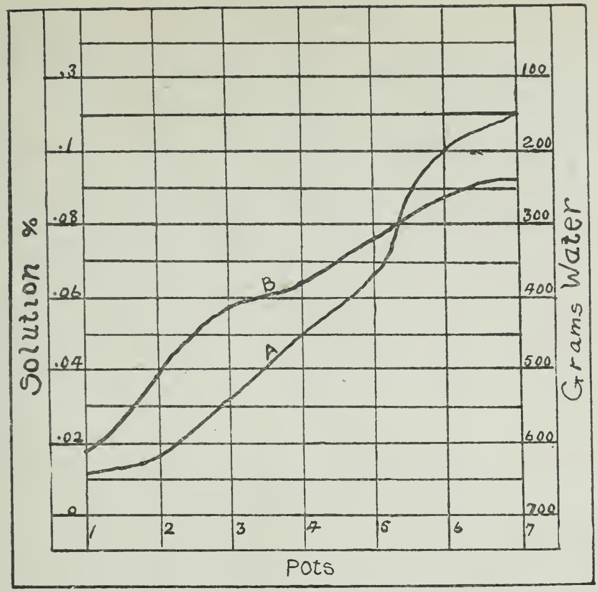

Fig. 17. Showing the relation existing between the concentration of the nutrient solution and the gram of water required to produce a gram of dry matter in wheat. (Taken from Table XXXV.). (A). Solution per cent. (B). Grams water per gram of dry matter.

TABLE XXXVI.

Effect of Concentration of Culture Solution on the Development of the Wheat Plant Grown in Pure Quartz Soil.

Strength of Solution in Per Cent	Grams of Total Plant: Stalks and Roots	Grams of Stalks only	Grams of Roots only	Grams of Ash: Whole Plant
.0125	5.8126	3.2748	2.5378	.4696
.0166	7.0718	4.2006	2.8712	.4786
.0333	18.1330	10.5546	7.5784	1.4948
.0500	29.8700	23.0014	6.8686	2.3293
.0666	36.6578	26.5632	10.0946	3.2720
.1000	80.3668	66.4430	13.9238	6.9532
.2000	31.1919	25.7963	5.3946	4.1432

TABLE XXXVII.

Effect of Concentration of Culture Solution on the Percentage Devlopment of the Wheat Plant Grown in Pure Quartz Soil.

Strength of Solution in Per Cent	Per Cent of Whole Plant as Stem andLeaves	Per Cent of Whole Plant as Roots	Per Cent of Ash in Whole Plant
.0125	56.4	43.6	8.07
.0166	59.4	40.6	7.76
.0333	58.2	41.8	8.24
.0500	77.0	23.0	7.80
.0666	72.4	27.6	8.93
.1000	82.7	17.3	8.65
.2000	82.7	17.3	13.30

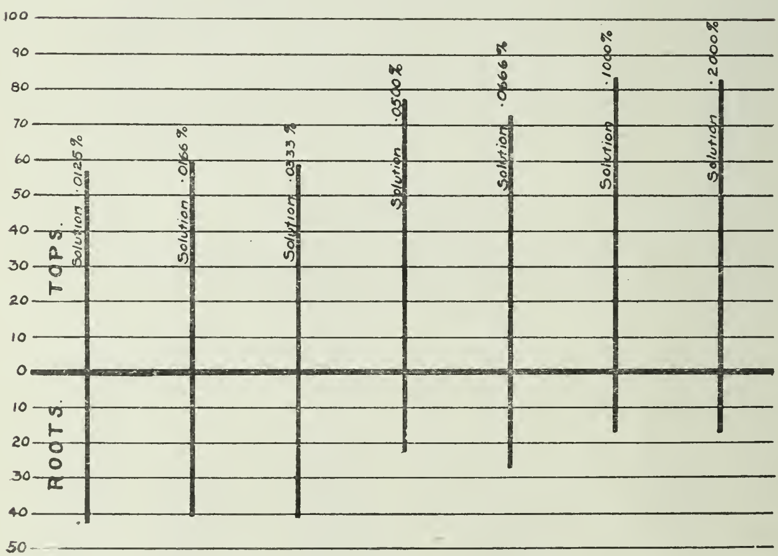

Fig. 18. The influence of the concentration of culture solution on the relative percentage development of roots to tops. Wheat grown in pure quartz soil.

Table XXXVII. presents some very interesting economic considerations as disclosed by the culture solution experiments. Of the total dry matter produced from the dilute solutions a very large proportion is contained within the root system. It is evident that plants grown in dilute soil solution, such as would be provided by an infertile soil, expend a large proportion of their energy in developing an extensive root system at the expense of stem and leaves. Of the total plant produced under such conditions a smaller amount is available for useful purposes. This condition is very strikingly illustrated in Fig. 13, which shows the relative development of roots and tops in the wheat plants grown in different concentrations of the culture solution.

FALLOWING AS A FACTOR INFLUENCING THE WATER REQUIREMENTS OF PLANTS.

The practice of summer-fallowing during alternate years, followed in most dry land sections, undoubtedly tends to increase the availability of the plant food materials in the soil, thereby increasing the strength of the soil solution during the crop year, and thus permitting a more economical use of the soil water by the plants.

In the spring of 1913 eight of the tanks described on page 11 were selected to determine the water requirement as affected by summer-fallow or previous cropping of the soil. The soils in these tanks had not been disturbed since the previous harvest. Two tanks that had grown wheat and two that had been summer-fallowed the previous season, were planted to wheat. Likewise, two tanks that had grown beans and two that had been summer-fallowed the previous season were planted to beans.

Table XXXVIII. shows that wheat grown on summer-fallowed soil used 31% less water to produce a pound of dry matter than did the same variety of wheat when grown in soil that had produced wheat the year previous. Beans used 19% less water per pound of dry matter on summer-fallowed soil than on one that had grown beans the previous year.

This is a remarkable saving of soil moisture. It would seem that summer-fallowing in the arid regions serves a double purpose, first to conserve or store a season's precipitation, to be used the following season, and second to set free

by judicious tillage a liberal supply of plant food materials, thereby increasing the available amounts of these materials in the soil solution, in consequence of which the plants are able to make a more economical use of the moisture stored within the soil.

TABLE XXXVIII.

Fallowing as a Factor Influencing the Water Requirements of Plants.

Crop and Previous Soil Treatment.	Pounds of Water Transpired per Pound of Dry Matter Produced.
Wheat—On Soil Cropped to Wheat the Previous Season	518
Wheat—On Soil Summer Fallowed the Previous Season	341
Less	177 or 34%
Beans—On Soil Cropped to Beans the Previous Season	424
Beans—On Soil Summer Fallowed the Previous Season	345
Less	79 or 19%

In this section of the country receiving 18 inches or more of rainfall, however, moisture is not the limiting factor in crop production, therefore, any system of cropping (see p. 48), tillage, or judicious use of manures and crop residues that tend to maintain a liberal supply of plant food and moisture without summer-fallow, will be of much greater value to the producer and offers a field for more experimental work.

INDIVIDUAL PLANT FOOD ELEMENTS AS FACTORS INFLUENCING THE WATER REQUIREMENTS OF CROPS.

If any one of the necessary elements of plant nutrition is deficient in the soil solution, that element becomes a limiting factor, and the use of water by the plant is determined thereby, and not by the total strength of all salts combined.

It is very well known that for a unit of production all

kinds of plants do not use the same or similar amounts of individual plant food materials. A given solution, therefore, might be deficient in any one element for one kind of plant, and the same element be fully adequate or more than adequate to meet the requirements of a different kind of plant. Tables XXXIX. and XL. show something of the effect of weakening the individual plant food elements on the water requirements of oats. The plants were grown in two-gallon

TABLE XXXIX.

Effect of the Individual Plant Food Elements on the Water Requirements of Oats.

Solution	Grams Total Dry Matter Produced	Per Cent of Dry Matter as Roots	Grams of Culture Solution Used	Grams Solution per Gram Dry Matter
*Normal Solution 1% Culture Solution	102.14	8.44	39946	391
Ca .02% of amount in Normal Solution ..	48.22	7.12	15026	312
K .02% of amount in Normal Solution	110.04	8.96	44840	407
N .02% of amount in Normal Solution	8.97	17.83	3830	427
P .02% of amount in Normal Solution	6.91	10.77	3180	460

*Containing .1% of total salts of culture solution given on page 45.

TABLE XL.

Effect of Individual Plant Food Elements on the Water Requirements of Oats.
1915

Solution	Grams Total Dry Matter Produced	Per Cent Dry Matter as Roots	Grams of Culture Solution Used	Grams Solution per Gram Dry Matter
*Normal Solution (.1% Culture Solution ..	28.292	12.3	12671	447
Ca .01% of amount in Normal Solution....	29.280	10.0	13165	449
K .01% of amount in Normal Solution	14.986	13.6	7393	493
N .01% of amount in Normal Solution	14.072	43.2	7127	506
P .01% of amount in Normal Solution	6.610	17.5	3717	562

*Containing .1% of total salts of culture solution given on page 45.

glazed crocks and handled in the manner described on page 45. The results in Table XXXIX., are for the season of 1914, and those in Table XL. for the season 1915. While the individual elements were not diluted in 1914 to the extent they were in 1915, yet the relative importance of the individual elements on the water requirements of oats is the same for each season.

In connection with the results presented in Tables XXXIX. and XL. there has presented itself to us the question, "Are the differences as here shown due wholly to the lesser actual amounts of the individual elements present or are the results wholly or partly due to the differences in the osmotic equivalents of these different solutions?"

This season (1916) these same tests are being conducted with solutions all of which have the same osmotic equivalent, while at the same time the amounts of the individual elements differ. The results of these tests will be reported at some future time. However, if the difference in the osmotic equivalents of the solutions as here used affected seriously the water requirements of the plants grown, the results obtained where calcium and potassium were weakened, do not indicate it.

THE EFFECT OF ALKALI SALTS ON THE WATER REQUIREMENTS OF PLANTS.

In Tables XLI. and XLII. are given the effect of increasing concentrations of sodium carbonate, sodium sulphate, and sodium chloride on the water requirements of corn.

These plants were grown in pure quartz sand, which was supplied with a complete culture solution, plus a varying amount of the above alkaline salts. The complete culture soltion used was the culture solution of .10% concentration used with wheat.* The results are the averages of three crocks in each case.

It is very difficult to obtain satisfactory results with alkaline or saline solutions owing to the abnormal growth obtained. These results indicate that the addition of a small amount of alkali salts, introducing as it does an abnormal condition, decreases the total production and at the same

*See page 45.

time increases the water requirements. As the akkali content is gradually increased, the concentration of the solution becomes a very important factor in both production and water requirements.

It would seem that concentration even of non-essential salts in the soil solution has a marked tendency to cut down the water requirements of plants. The averages of all results as presented in Table XLII. show a material decrease in the water requirements of corn, with the increase of alkaline salts. Of the individual salts, sodium chloride was most influential in reducing the water requirements.

TABLE XLI.

The Effect of Sodium Salts (alkali) on the Water Requirements of Corn. Complete Culture Solution plus Progressive Concentrations of Alkali.

Solution	Grams Water Transpired	Grams Dry Matter Produced	Grams Solution per Gram Dry Matter
*Complete Culture Solution	653.2	2.117	309
Plus Na_2CO_3 .02%	388.7	1.062	366
Plus Na_2CO_3 .033%	526.5	1.527	345
Plus Na_2CO_3 .10%	390.9	1.471	266
Plus Na_2CO_3 .20%	42.1	.188	277
Plus Na_2CO_3 .333%	No Growth		
*Complete Culture Solution	799.9	2.521	317
Plus Na_2SO_4 .02%	752.0	2.289	328
Plus Na_2SO^4 .02%	595.1	2.070	288
Plus Na^2 SO^4 .10%	718.6	2.312	311
Plus Na_2SO^4 .20%	641.4	1.907	337
Plus Na_2CO^4 .333%	635.2	2.294	277
*Complete Culture Solution	748.7	1.915	391
Plus NaCl .02%	859.0	2.369	362
Plus NaCl .033%	590.9	1.512	390
Plus NaCl .10%	579.8	2.141	270
Plus NaCl .20%	248.8	1.008	247
Plus NaCl .333%	254.2	1.455	175

*Containing .1% of total salts of culture solution given on page 45.

TABLE XLII.

The Effect of Progressive Concentrations of Sodium Salts (alkalies) on the Water Requirements of Corn. Sumary of Results.

	Complete Culture Solution plus Na_2CO_3				
*Complete culture Solution	.02%	.033%	.10%	.20%	.333%
309	366	345	266	277	
	Complete Culture Solution plus Na_2SO4				
Complete culture Solutio	.02%	.033%	.10%	.20%	.333%
317	327	288	311	337	278
	Complete Culture Solution plus NaCl				
Complete culture Solution	.02%	.10%	.20%	.033%	.333%
391	362	390	270	247	176
	Average				
339	352	341	282	287	227

*Containing .1% total salts of culture solution given on page 45.

PREVIOUS CROPS AS A FACTOR INFLUENCING THE WATER REQUIREMENTS OF PLANTS.

The favorable or unfavorable effects of previous crop on succeeding crops has long been recognized. The reason for such effects are not fully understood tho it is generally believed to be due to the influence which the growing crop has upon specific soil reactions during the growing period. These reactions or their absence result in a favorable or unfavorable soil condition upon succeeding crop. Just what should be understood by favorable or unfavorable soil conditions will depend very largely upon the crops in question and the order in which they follow in the rotation. Favorable soil conditions result in the maximum availability of the plant food materials for the succeeding crops.

The growth of light feeding intertilled crops such as corn and potatoes undoubtedly leave a soil in much better condition to support succeeding crops than does the growth of heavy feeding non-intertilled crops such as wheat, oats, or barley.

In view of the foregoing it is not surprising that the influences of crops one upon another would materially affect their water requirements. The extent of such effects is

clearly shown in Table XLIII., where wheat followed wheat, oats, alfalfa, corn, and red clover respectively. This influence is more marked than is generally understood and is one of the most important points to be considered in establishing proper rotation of crops in the semi-arid sections. The crops mentioned in Table XLIII. were grown in tanks. (p. 11).

TABLE XLIII.

Previous Crop as a Factor Influencing the Water Requirements of Plants.

1913

Crop and Previous Crop	Pounds of Water per Pound of Dry Matter Produced
Wheat after wheat	487
Wheat after oats	400
Wheat after alfalfa	391
Wheat after corn	360
Wheat after clover	310

VARIETY AS A FACTOR INFLUENCING THE WATER REQUIREMENTS OF PLANTS.

XLIV.

Variety as a Factor Influencing the Water Requirements of Wheat.

1913

Variety of Spring Wheat	Pounds of Water Transpired to Produce a Pound of Dry Matter
Washington Bluestem	327
Washington 171	333
Little Club	338
Kubanka	334
Washington 143	429

Results with five varieties of spring wheat indicate that variety plays little or no part in determining water requirements of wheat. In Table XLIV. the results are very uniform with exception of Washington Hybrid No. 143. The result for No. 143 is possibly due to the fact that this variety is for this section both a spring and winter wheat, but appears to give better results as a winter variety. The habits of growth of No. 143 hybrid when sown in the spring resembles closely that of winter varieties when sown in the spring in heavy

foliage covering the ground before sending out stems. This heavily leaved condition and abnormal growth might account for the higher water requirement in this instance.

STAGE OF DEVELOPMENT AS A FACTOR INFLUENCING THE WATER REQUIREMENTS OF PLANTS

Several trials resulted uniformly in mature plants giving a marked decrease in the water requirements per pound of dry matter, as compared with immature plants in several stages of development. In all instances the water requirements per pound of dry matter decreased as the stage of development increased. Table XLV. presents several trials with different crops in different soil media, with uniform results all pointing to the same conclusions. Two gallon jars (see p. 44) were used in the experiment and crops were grown in the green-house in the spring of 1913. The first column of Table XLV. gives the age of the plants in days.

TABLE XLV.

Stage of Development or Age as a Factor Influencing the Water Requirements of Plants.

Days After Germination	Total Grams of Dry Matter Produced	Total Grams of Water Transpired	Grams of Water Transpired per Gram of Drq Matter Produced
Wheat Grown in Pure Quartz Soil—Nutrient Solution, .1000%			
50	3.1145	1315	422
90	22.2637	8040	362
137	99.7445	26100	262
Wheat Grown in Palouse Silt Loam.			
50	2.0785	1230	592
90	12.6056	5500	436
137	28.6346	8930	312
Oats Grown in Palouse Silt Loam.			
30	2.5763	1335	519
60	11.7667	5595	475
90	58.9037	21770	369

PERCENTAGE OF CAPILLARY SATURATION AS A FACTOR INFLUENCING THE WATER REQUIREMENTS OF PLANTS.

XLVI.

Percentage of Capillary Saturation as a Factor Influencing the Water Requirements of Plants.

Wheat Grown in Pure Quartz Sand—Nutrient Solution .1000%

Per cent of Capillary Saturation	Grams Water Transpired per Gram of Dry Matter Produced
33	242
66	279
Wheat Grown in Palouse Silt Loam.	
33	274
66	287

The exact percentaage of capillary saturation of a soil, provided it is maintained above the wilting point and below complete saturation, seems to have but a slight effect on the water requirements of plants. Whether soils maintained for several seasons at different capillary saturations would result in different water requirements for the same kinds of plants is yet to be determined. Trials with pure quartz sand with complete culture solution and with Palouse silt loam gave similar results for the same capillary saturation indicating that that the soil type is not an important factor in this connection.

In conclusion the writers wish to acknowledge their indebtedness to James A. Dickson, Pandurang Khan-Khoje, and Charles A. Thompson, graduate students in the Department of Soils, for valuable assistance in these investigations.

SUMMARY

The numerous conditions surrounding plants that influence their growth and water requirement and the adaptability and habits of the plant to meet these conditions, make it impossible to give and deffinite water requirement for any plant, or even to give the relative order in which

given number of varieties will stand in respect to this factor.

The average water requirement of six cereal crops was 312, and for four legumes, 429.

The daily amount of water transpired by wheat, corn, oats, and peas increased until about the beginning of the ripening period; from this time there was a gradual decrease up to maturity.

The depth to which field crops took moisture was: wheat, 9 feet; oats, 8½ feet; barley, 8 feet; peas, 6 feet; millet, 5½ feet; corn, 5 feet; beans, 5 feet.

The crops that took the soil moisture from the greatest depth also had the greatest water requirement.

Tanks proved to be equal to field plats in determining the water requirements of plants.

The ash content of different plants increased with the increased water requirement.

Plants grown in culture solutions varying in concentration from .01% to .1% increase in total dry matter produced and decreased in water requirement. The average of three trials, a .01% concentration gave a growth of 3.152 grams of dry matter and a water requirement of 729; in a .1% concentration, 39.2226 grams of dry matter and a water requirement of .381.

The percentage of roots in the total dry weight decreased from 43.2% in a .0125% concentration to 17.3% in a .1% concentration of a nutrient solution. In like manner the water requirement was reduced from 605 to 262, respectively. The above results indicate that weak soil solutions cause an increased root development in plants.

The water requirement of wheat was 34% less, and for beans 19% less when grown on summer-fallowed soil than when grown on cropped soil.

When any of the essential plant food elements—nitrogen, potassium, phosphorus, and calcium—were reduced to .02% and .01% of that contained in a normal solution used in culture solution work in this bulletin, the reduction of calcium and potassium made good growths and nitrogen and phosphorus poor growths. The water requirement was increased in each case except when calcium was deficient.

When nitrogen was reduced to .01% of the normal solution, 43.2% of the total dry matter produced was roots.

When calcium was reduced to .01% of the normal solution, only 10% was roots. Consequently a soil with a low nitraate content causes a plant to develop an abnormally large root system.

Increasing the concentration of a complete culture solution by addition of alkali salts, viz., sodium carbonate, sodium sulphate, and sodium chloride, decreased the water requirement until the solution became so concentrated to inhibit growth.

The water requirement of wheat was less when grown on soil that had grown legumes and intertilled crops the previous season than the soil that had grown cereals.

The difference obtained in the water requirement due to variety in spring wheat is small.

There is a decrease in the water requirement of wheat and oats with increase in age.

The percentage of capillary saturation of the soil in which plants are grown is not an important factor in the water requirement of plants, provided the percentage of moisture is maintained considerably above the wilting point.

The results of these investigations indicate that any condition which disturbs the normal life processes, be it soil, atmospheric, or pathological; increases the water requirement to just such a degree as it depresses the normal functionings of the plant.

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DIVISION OF BOTANY

Plant Physiology

A New Method for the Preparation of Pectin

By

J. S. CALDWELL

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A New Method for the Preparation of Pectin

By

J. S. Caldwell

Although fruit jellies are among the most palatable and desirable fruit products which can be included in the dietary, the volume of such jellies made and consumed in this state is far smaller than it should be. The total production of jellies by commercial plants is comparatively small, and the practice of making a supply for the family in the home is not general. The commercial jellies are expensive and their free use is consequently restricted to the well-to-do, who spend considerable sums for such products made outside the state, while there is an annual waste in our households and commercial canneries of a very large volume of valuable jelly-making material. There are several reasons why failure to utilize this material occurs. In the household, considerable quantities of juices of uncooked strawberries, raspberries, cherries and loganberries may be accumulated during the canning season, while in the commercial canneries, the loss of juice which occurs in pitting cherries may amount to 35 to 65 gallons per ton of fruit. For reasons to to be immediately stated, it is impossible to make good jellies of these juices without the addition of apple, pear or quince juice, hence if they are to be used it is necessary to sterilize, seal, and store them for several months until apples or pears become available. In commercial canneries and in very many homes this is regarded as involving too much labor, and in consequence these juices are discarded.

The making of jelly from any fruit depends upon the presence therein, in very definite proportions, of three essential constituents: pectin, acid, and sugar (3, 5, 6, 7, 10, 11). The amount of sugar in any fruit juice is always defic-

ient and must be supplemented, while the relative amounts of pectin and acid vary widely in the different fruits, as has been shown by the extensive studies of Cruess and McNair (3). If the amounts of pectin and of sugar be properly adjusted with reference to the acidity of the juice, it is possible to make a palatable jelly of excellent physical appearance by adding pectin, a fruit acid, and sugar to distilled water and boiling for the proper time.

The difficulties encountered in attempting to make jellies from strawberries, peaches, loganberries, and cherries is due to the fact that none of these fruits contain sufficient quantities of pectin, in comparison with their acid content, to cause gelatinization or jellying, no matter how much sugar may be added. When the housewife mixes apple or quince with these fruits, she is simply increasing the pectin content of the mixture by addition of a fruit rich in that constituent, thus making gelatinization possible (9).

Some disadvantages arising out of the use of apples as a source of pectin, aside from the fact that they are not available at the season at which berries and soft fruits are plentiful, are that in order to make a jelly of good physical appearance, considerable quantities of apples must be used and in some cases the delicate flavor of the berry is obscured or well-nigh lost. To avoid this difficulty, commercial preparations of pectin in concentrated form may be employed, but the cost of these preparations is unnecessarily high and their use is correspondingly restricted. If jelly made from a mixture of apples and berries, or from berries to which water extracts of dried peels and cores of apples have been added, is offered for sale, the fact that the jelly is a blend must be declared on the label, and such blends generally bear a price only slightly higher than that of apple jelly. If pectin be added to a jelly offered for sale, the label must bear the statement "contains added pectin," but such jellies are not discriminated against in the markets.

Some experiments carried on in this laboratory during the past year have had as their purpose the development of simple, practical methods whereby such cheap and abundant materials as cull apples, apple peels and cores, or pomace from cider presses may be utilized as a source of pectin for jelly-making, without any of the disadvantages which accompany the use of the fruit itself and without the use of large

quantities of alcohol for precipitating the pectin, as is the case in Goldthwaite's method of preparing pectin from orange and lemon peel (5, 6, 7). Such methods have been worked out in a form which makes it possible for the housewife or the commercial jelly-making concern to prepare such quantities of concentrated pectin as may be desired and store it until it may be needed, without the use of special equiment. In order to make some features of the method clear it is necessary to state briefly some general facts in regard to the chemistry of the pectins and their occurrence in plant tissues.

The term "pectic compounds" is applied to a group of substances occurring in plants which have the common property of causing gelatinization or jellying of fruit juices or watery extracts of fruit pulps in which they are present or to which they may be added. Chemically the pectins are closely related and are probably all derived by slight modifications from one mother-substance known as pectose; they belong to the group of complex carbohydrates known as the polysaccharides and are closely allied in composition and properties to the natural plant gums and mucilages. There is an extensive literature dealing with the chemistry of the group and describing a great number of pectic derivatives, but the work therein reported was for the most part done prior to the development of modern methods of chemical investigation and the results leave us with highly confused and contradictory conceptions of the chemistry of the pectins. This literature will not be reviewed here, as excellent summaries have been given by von Lippmann (12), Czapek (4), and Bigelow, Gore, and Howard (1). The following outline presents the more important generally accepted facts in so far as they are essential to our present purpose.

Representatives of the pectins are found in some quantity in practically all parts of green plants and are relatively most abundant in young, rapidly growing parts, in fleshy roots such as those of carrot, beet, turnip, and artichoke, and in succulent fruits such as apple, quince, pear, currant, and gooseberry. In the immature fruit, the pectic compounds occur as constituents of cell-walls, in which they make up a thin central membrane which is covered upon both surfaces by a layer of cellulose. In part these compounds are in combination with calcium as calcium pectate, in part they consist of a highly complex compound, pectose, which is re-

garded as the mother-substance from which the simpler pectic compounds are derived. Both pectose and calcium pectate are insoluble in the cell-sap or in water, and they give to the young fruit much of its characteristic hard, woody nature.

As the fruit becomes mature, physical and chemical changes in these pectic compounds set in, as a result of which they absorb water, swell, and pass into a gelatinous condition in which they are slightly soluble in water. By reason of the fact that each cell wall consists of two layers of cellulose deposited upon a central layer of pectose, the absorption of water and swelling by the pectose forces the cells apart, loosens them one from another as the bricks of a wall would be loosened by the removal of the layers of mortar, and converts the previously firm, compact flesh into the soft, loose mass of separated cells which makes up the pulp of ripe fruit.

The term pectin is applied to the gelatinous, water-swollen substance or mixture of substances resulting from this change. Since pectin is slightly soluble in cold water, the juices pressed from ripe fruits may contain small amounts in solution, but these never represent more than a very small fraction of the total quantity present in fruits. Consequently, the pomace resulting from the pressing of apples for cider contains practically the whole of the pectin originally present in the fruit. Moreover, since pectins are uniformly distributed throughout the fruit, a given number of pounds of peels and cores contain as much as an equal weight of whole fruits. This fact has long been utilized in a practical way in Eastern evaporators and canneries, which dry their apple waste for subsequent use in jelly and vinegar making.

It follows from what has been said above that in order to extract the pectin completely from any fruit, it must be treated for some time with hot water, which slowly brings pectin into solution. It has been shown by Bigelow, Gore, and Howard (1) that six hours boiling with water under a reflux condenser, with change of water at the end of every hour, does not completely remove all pectin from apple pulp previously freed of sugars and other materials soluble in cold water, alcohol, or ether. Goldthwaite (5, 6, 7) has also shown that when apples are covered with water, brought to a boil, crushed, drained through cheesecloth, returned to a

fresh quantity of water and again heated, five successive extractions with water are necessary in order to exhaust all pectin, and these results have been confirmed in this laboratory. In consequence, the pectin from a given quantity of fruit is dissolved in a very large volume of water, and the problem to be solved is the problem of reducing this dilute solution to a small volume. Pectin cannot be prepared by evaporating a dilute solution in water unless the work is carried on in a partial vacuum at a low temperature, since long-continued boiling brings about chemical changes which involve the loss of power to produce gelatinization. It can be precipitated from such solutions by the addition of alcohol, but precipitation does not occur until the percentage of alcohol in the mixture has reached 51%. This necessitates the use of large quantities of alcohol which it is impossible to recover except by repeated distillation and makes the method entirely too expensive for general use. It is also possible to employ chemical methods of precipitation, but these necessitate subsequent treatment to free the precipitate from the metallic salts or other agents employed, and such methods are too complicated for use outside the laboratory.

The method employed for securing concentrated solutions of pectin in the writer's laboratory was suggested by the method for concentrating fruit juices developed by Gore (8, 9). This method consists essentially in separation of a portion of the water of the juice by freezing, removal of the concentrated liquid from the ice by a centrifugal machine, and repetition of the process until the desired concentration has been attained. This method has been so simplified and adapted that it may be employed on the small scale by any housewife. The following description of a typical experiment will make the method clear:

20 kilos (44 pounds) of mature Winesap culls were ground to a fine pulp in a small meat chopper, placed in a graniteware vessel, enough cold water—3000 cc.—added to cover them, and slowly heated to boiling. After two hours gentle simmering the whole was placed in a double muslin bag and suspended over a vessel to drain. When dripping had entirely ceased the pulp was returned to the cooker, 2500 cc. cold water added, and again slowly cooked. Four successive cookings of approximately two hours each extracted the

pectin so completely that the extract no longer gave an appreciable precipitate of pectin when allowed to fall drop by drop into strong alcohol. The pulp was then gently pressed to extract as much liquid as could be forced out without forcing fragments of pulp through the muslin, and the various extracts were collected and measured. 12,000 cc. of water had been added during the cooking, and the total quantity of extract measured 23,456 cc. (24.8 quarts).

This liquid was now placed in tall, enamel-lined tin cans and subjected to freezing by exposing it on a window-sill over night, at a temperature of 15-20° Fahr. The cans were filled next morning by a mass of knifeblade-like platelets and spicules of pure water ice, holding between them a quantity of liquid containing all the solids of the extract. The cans were emptied into a large graniteware vessel, the ice was crushed by the use of a wooden mallet, and the liquid separated from the ice by the use of an ordinary cream separator. The bowl of the separator was filled with the mass, and the machine was turned slightly faster than would be done for separating cream. Five minutes sufficed to separate the liquid completely from a charge of ice, which was then perfectly clear. This treatment reduced the original 23,456 cc. to 9308 cc., which was returned to the cans and again frozen and separated, yielding 5626 cc. A third and a fourth freezing and separation reduced the volume of 2260 cc. The liquid was now a very dark brown color and had the consistency of a thick syrup, as it contained not only the pectin, but also the sugar and the coloring mater of the entire extract. (Nitrogenous constituents had been coagulated by the long heating to which the fruit had been subjected, hence did not pass into the extract).

The extract was now further concentrated by placing it upon a shelf at such a distance above a radiator that it would be kept at a temperature of 70° C. (158° Fahr.). Here it remained four days, becoming reduced to 1509 cc., or less than one-fifteenth its original volume, when solidification at the surface practically stopped further loss of water. The extract was now treated by the method used by Goldthwaite (5, 6, 7) for precipitating pectin. The mass was slowly poured from a beaker into a vessel containing 1600 cc. of 95 per cent alcohol, which caused precipitation of the pectin as a gelatinous, rubberlike mass, the sugars and coloring

matter for the most part remaining in the alcohol. The mass of pectin was collected on a cheesecloth filter, the alcohol worked out of it with a spatula, and it was then washed with previously filtered alcohol which had been used in the precipitation, followed by small quantities of fresh alcohol. To further purify it, it was now dissolved in 1000 cc. of lukewarm water, which required occasional stirring for several hours to secure complete solution, and reprecipitated by pouring into 1000 cc. of 95 per cent alcohol, after which the alcohol was pressed out with a spatula. The mass of pectin was then dried slowly over the radiator already mentioned at a temperature of 70° C. The dry pectin is a whitish gray mass easily ground into a grayish powder which dissolves readily in warm water, and has not undergone change upon keeping in a corked bottle on the laboratory shelf for more than five months. A good jelly was made by adding 1 per cent by weight of this powder to water in which ½ per cent tartaric acid had previously been dissolved, adding 65 per cent by weight of sugar, and boiling for 15 minutes.

The method just described has two disadvantages in that it requires the use of a cream separator, which is a common but by no means universally available piece of equipment, and in that a considerable volume of alcohol is required for precipitating the pectin from solution, a total of 2800 cc. having been used in the experiment just described. Alcohol of 95 per cent strength is quite expensive, and is so diluted by one using as to be of no further use and must be lost unless facilities for redistilling it are at hand. Hence some further experiments had as their purpose the avoidance of these disadvantages.

It was found that if the mass of ice obtained by freezing were thoroughly crushed, transferred to a muslin bag of double thickness, brought into a warm room, suspended over a suitable vessel, and thoroughly stirred with a large spoon or strip of wood at intervals for a period of 25 to 30 minutes, the liquid could be quite completely drained out before much melting of the ice had occurred. It was always possible to reduce an extract to one-twelfth to one-tenth its original volume by four successive freezings and drainings through cheesecloth, and repeated tests in comparison with the separator method shows that the loss of pectin did not exceed 1.5 per cent of the total quantity present.

It occurred to the writer that if the acidity of the concentrated extract were reduced to such a point that the pectin would not be affected thereby, it should be possible to keep such a preparation for a long period without deterioration, as the very high content of sugar and the absence of nitrogenous material makes such an extract a very unfavorable medium for the growth of fungi. This hypothesis was tested out in the following way: 12,000 cc. of water extract made from 10 kilos of Ben Davis culls was reduced by two successive freezings to 4763 cc. The liquid was transferred to a tall vessel and 12 grams powdered lime carbonate (precipitated chalk) was slowly added with constant stirring. Lime carbonate reacts with the malic acid of the juice to form an insoluble salt, calcium malate. As soon as the addition of the carbonate had been made, the liquid was thoroly stirred and divided into two equal parts in order that two methods of removing the calcium malate might be tested.

One lot was immediately transferred to a graniteware vessel, brought to a boil and filtered through filterpaper while boiling. Filtration was efective in removing the calcium salt but was rather slow. Since filterpaper and filtering apparatus are not usually available in the household, the second method now to be described is preferable for home use.

The second lot of extract was allowed to stand undisturbed for 12 hours after the addition of the lime carbonate. At the end of that time the calcium malate formed had collected at the bottom and upon the sides of the vessel as a thin, granular precipitate. The clear liquid could be siphoned off without disturbing this precipitate, and it was also possible by employing care to pour it off without the loss of more than a few cc.

The two portions of extract, after precipitation and separation of their acid as the calcium salt, consisted of 2365 cc. each. They were kept separate, reduced to 725 and 713 cc. respectively by two successive freezings, then transferred to beakers and reduced by slow evaporation over a radiator at 70 C. to a volume of 400 cc. each. They now had the consistency and much the color of good tomato catsup. Two grapejuice bottles were sterilized by thorough boiling and the contents of the two beakers were transferred to them and

sealed. These bottles have been kept upon an open laboratory shelf for four and one-half months, have been twice opened and resealed after removal of a part of the contents, and are at the present time free from evidence of growth of bacteria or fungi, while the pectin retains its power of causing gelatinization without decrease. Other preparations made without removal of the acid have undergone a slow deterioration of power to cause gelatinization and are now practically inert, having lost somewhat more than half their original efficiency in the first three weeks after their preparation. Preparations of dry pectin made by precipitating with alcohol and drying at a low temperature have undergone no discoverable change in their efficiency, when kept in sealed bottles, during four and one-half months.

The concentrated pectin solution made by freezing and evaporating down is of course very far from pure, since it contains not only the sugars but also the coloring matters and such flavoring substances as have not been volatilized by heat as were present in the apples used. Its addition to any fruit juice will not produce greater change in color and flavor than would be produced by the addition of an equivalent volume of apples, and will not perceptibly affect any but the most delicate jellies. The powdered pectin is practically free from coloring matter, has no discoverable apple odor or taste, and will not cause deterioration in flavor of even the most delicate jellies, to which its use may well be restricted because of the greater labor and cost of preparation. Since either preparation represents the entire quantity of jelly-forming substance present in the volume of apples, pears, or quinces from which it is made, the housewife who has had experience in the use of these fruits as an aid in jelly-making can readily judge of the amount of the concentrated preparation which it will be necessary to employ. On this subject the work of Goldthwaite on the making of jellies with the aid of pectin prepared from orange and lemon peel will be found extremely helpful (5, 6, 7).

The amount of pectin present in the apple is stated by Browne (2) as varying between 0.2% and 0.6% of the fresh weight of the fruit. Bigelow, Gore, and Howard (1) found that 1.3% of the fresh weight of the fruit was rendered soluble when the marc, freed of sugar and all substances soluble in cold water and alcohol, was boiled for six hours with hour-

ly changes of water under a reflux condenser, but these extracts undoubtedly contained much material other than pectin.

Mention of experiments made with special laboratory equipment and by the use of exact chemical methods have been purposely omitted, since it was the purpose of the work to develop a method for the preparation of pectin which could be carried out in any kitchen. A commercial plant desiring to make pectin in quantity from its apple and pear refuse can utilize the brine tanks of an ice plant for freezing its extracts at any season, and a milk separator or centrifugal machine can be employed for separating the ice, while a vacuum drying apparatus, when available, can be employed for drying down the extract to any desired volume at low temperature. The housewife who desires to prepare a supply of pectin for the next season can utilize any period of cold weather to do so, by making her extracts, freezing them outside, draining through muslin, freeing from acid by the use of calcium carbonate at the rate of 1/8 ounce for each gallon of the orignial extract at any stage of the process when convenient, completing the reduction in volume by keeping at 70° C. by placing them near the kitchen stove, and finally sealing the product in sterilized bottles or fruitjars until needed. No special equipment is needed, and the only cash outlay involved is the purchase of the precipitated chalk (powdered lime carbonate) used. Lime carbonate is a cheap chemical obtainable at every drugstore at prices ranging from 15 to 30 cents per pound. The work may be done at and convenient time during cold weather, but should not be needlessly delayed until late in the spring, as the amount of pectin which can be extracted from apples, pears, and other fruits slowly decreases with storage by reason of slow chemical changes which go on in the fruit.

SUMMARY

1. Pectin can be completely extracted from fruits containing it by successive extractions with boiling water.

2. An aqueous solution of pectin can be concentrated by subjecting it to freezing, separating the liquid from the ice by the use of a cream separator or by draining the crushed ice through muslin, and repeating the process several times, finally completing the concentration by evaporating down the residue at a low temperature.

3. Such concentrated extracts retain their gelatinizing properties perfectly for long periods if the contained acid is removed by precipitation with calcium carbonate prior to the final concentration. The use of 1 ounce of calcium carbonate for seven to eight gallons of water extract will reduce the acidity sufficiently to secure perfect preservation.

4. If desired, precipitation of the pectin from the concentrated extract by alcohol may be resorted to in order to secure a tasteless, odorless product for use in the more delicately flavored jellies.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF BOTANY
Plant Physiology

THE EVAPORATION OF FRUITS AND VEGETABLES

By
J. S. CALDWELL

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THE EVAPORATION OF FRUITS AND VEGETABLES

BY

J. S. CALDWELL

Plant Physiologist

SUMMARY

A very considerable portion of the annual crop of fruits and vegetables of the State of Washington is at present wasted by reason of the absence of by-products plants for working up such materials as are not marketable in the fresh state.

Evaporation is the least expensive and most generally applicable method of preserving perishable fruits and vegetables. Evaporated food stuffs retain all their nutritive and dietic value and can be preserved indefinitely in ordinary storage, while the reduction of their original weight and volume to one-third to one-eighth greatly facilitates transportation.

Three types of evaporator: the kiln or hop-kiln evaporator, the prune tunnel or prune drier, and the Carson-Snyder or all-purpose evaporator, are recommended as especially adapted for use in the commercial fruit-growing and vegetable-growing districts of Washington. In any particular case the choice of one of these types must be determined by the character and variety of material to be handled.

The kiln evaporator should be the type constructed in districts in which apples are the chief or only fruit to be dried. While designed primarily for the evaporation of apples, the kiln drier can be employed in the drying of berries or of such vegetables as potatoes, carrots, cabbage, and onions, with perfectly satisfactory results. It is not well adapted to the drying of prunes, and peaches and apricots are more readily dried upon types of driers employing trays. The cost of a kiln evaporator, both for construction and for operation, is slightly less than that of a plant of equal capacity of either of the other types described.

In districts having a wide variety of materials and espec-

ially of fruits to be preserved by evaporation, the plant should be a tunnel or an all-purpose evaporator, as the longer working season and the larger volume of output will offset the slightly greater costs of construction and operation.

The tunnel evaporator is especially adapted to the drying of prunes, but gives equally satisfactory results with other fruits and with vegetables. The all-purpose evaporator differs materially in the principles involved in its construction and operation from the tunnel drier, but has practically identical construction and operation costs.

In order to yield a safe margin of profit to the operator, an evaporator of any one of these types should have a capacity of not less than ten tons of fresh material per day and should be completely equipped with modern labor saving machinery.

Detailed discussion of the construction of buildings, the installation of machinery and equipment, the preparation of the various materials for drying and their subsequent care, with estimates of the cost of construction and operation of each of these three types of evaporators are given in subsequent pages.

INTRODUCTION

The present publication is, in part, a revision of Bulletin No. 131 of this Station, which dealt in detail with the construction and operation of evaporators designed primarily for the drying of apples. Much of the subject matter of that bulletin, which is now out of print, is reproduced here without essential change, but new sections discussing in detail the drying of cherries, berries, peaches, apricots, prunes, and the various commoner vegetables have been added, with somewhat full directions for preparing the various materials for drying and for storing and packing the dry products. The writer's intention has been to prepare a rather complete handbook for the guidance of beginners in the evaporating industry, discussing not only the types of evaporators best suited to specific purposes, but also every stage of the process of preparing and drying each of the fruits and vegetables which can be handled through the agency of the evaporator.

THE FUNCTION AND VALUE OF BY-PRODUCTS PLANTS

Permanence and stability of the fruit industry of any district which is producing fruit in commercial quantities can be attained only by the development of by-products plants. In years of normal production they absorb the unmarketable, blemished, undersized fruit at prices which repay cost of handling and contribute something toward the maintenance of the orchard, while in years of overproduction or of congested markets they keep the lower grades of marketable fruit, or the surplus of all grades, out of the fresh fruit market, thus holding prices above the cost of production and preventing heavy losses of valuable material. Consequently any fruit growing district which has not developed by-products plants may be said to be in a condition of unstable equilibrium; it is subject to all the fluctuations in fresh fruit prices resulting from overproduction at home or elsewhere, reduction or congestion of transportation facilities, cessation of foreign purchases, or other causes, without being able to protect itself. Hence every one of the older important fruit growing districts has been forced to develop the by-products industry as a means of self-protection. But it is also true that wherever the canning or evaporating of fruits becomes established, it gradually assumes the importance of a primary industry, and a considerable portion of the annual crop is handled through the by-product plant, irrespective of conditions in the fresh fruit market. This is conspicuously the case in the fruit growing districts of California and New York, and their history must be repeated in every other district which produces a volume of fruit in excess of the demands of immediately adjacent territory.

The fruit growers of Washington, in common with those of the Northwest generally, suffer very severely from the lack of means of utilizing their surplus products. Increasing rigidity in the system of grading employed, accompanied by the aging of the apple orchards and by some relaxation of the scrupulous care given them in earlier years, is resulting in the annual production of an enormous volume of low grade and

cull fruit. This material is largely or wholly lost, though in some part it finds purchasers in the state or in adjacent states, but at prices which, at least in recent years, are considerably below the average cost of production (1, 2, 3, 4). Furthermore, such sales of low grade fruit obviously decrease the demand for the higher grades, increase the difficulty of transporting the better grades to the more distant markets which they are forced to seek, and thus increase and intensify the difficulties of the marketing problem.

The rapid increase in the production of pears, peaches, apricots, prunes, cherries, and berries in the state has led to a serious condition in some important fruit growing districts. The volume of these materials demanding movement to distant markets is such as to tax all available means of transportation to the utmost, even under normal conditions, and any reduction or congestion of such facilities during the shipping season inevitably results in large losses of fruit which it is impossible to hold in storage. The production of the immediately perishable soft fruits has outgrown the demand within the territory which can be supplied by shipment by the usual methods, and it has been shown that while some of these fruits can be shipped for long distances, good results can be secured only when all the operations of picking, handling, and packing are conducted with a degree of care which it is practically impossible to secure, under existing conditions of labor supply, in commercial orchard practice (5, 6). For these reasons

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1. Miller, G. H., and Thomson, S. M.—The Cost of Producing Apples in Wenatchee Valley, Washington, U. S. Department of Agriculture. Bulletin 446, 1917.
2. Thomson, S. M., and Miller, G. H.—The Cost of Producing Apples in Hood River Valley. U. S. Department of Agriculture. Bulletin 518, 1917.
3. Thomson, S. M., and Miller, G. H.—The Cost of Producing Apples in Western Colorado. U. S. Department of Agriculture. Bulletin 500, 1917.
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5. Ramsey, H. J.—Factors Governing the Successful Shipment of Red Raspberries from the Puyallup Valley. U. S. Dept. of Agriculture. Bulletin 274, 1915.
6. Ramsey, H. J.—The Handling and Shipping of Fresh Cherries and Prunes from the Willamette Valley. U. S. Dept. of Agriculture. Bulletin 331, 1916.

the losses sustained by growers of these various fruits, while somewhat less regular in their occurrence and much less appalling in their magnitude than those falling upon the apple growers, are nevertheless such as to make the business one which involves great risks of financial disaster.

It is obvious that the fruit growing districts of Washington, with greater distances to markets than the older fruit-growing states, can not continue to lose outright any considerable portion of their product. Nor can they continue to engage in competition with one another for the privilege of overloading nearby markets with undesirable varieties and lower grades of all varieties at prices below cost of production. They must follow the example of every one of the older fruit-growing districts, which have found stability and permanence for the industry only in such degree as they have limited their output of fresh fruits to the absorbing capacity of their markets and have ended orchard losses by developing by-product plants to utilize the surplus.

There thus exist very strong prudential and economic reasons for the establishment of by-products plants throughout this territory. To these there is now added the pressure of necessity. There is at the present time an almost unparalleled shortage of food supplies of every character in much of the world, and it is certain that this shortage must be very largely met by the United States through increased production and by more complete conservation and utilization of the crops already being produced. It has been emphasized by the highest authorities that the preservation of every pound of food material produced is an imperative necessity if we are to avert an actual famine of almost world-wide proportions, and such authorities are insisting that in the face of the grave situation confronting us, the preventable waste of materials having food value is a treasonable and criminal act which should be made punishable by law. It must not be forgotten that in supplying the actual necessities of life, fruits and vegetables are as indispensable as grains and meats, and that without them it is impossible for human beings to maintain continued normal health. But fruits and vegetables retain all their nutritive

value and their health-preserving powers after having been subjected to drying, which eliminates all inedible portions and converts the material into non-perishable form while reducing its weight by three-fourths to seven-eighths. In supplying the necessities of the famine-threatened foreign countries, only indispensable materials, reduced to the smallest possible weight and compass, can be employed, and dried fruits, possessing as they do an energy-yielding food value equal, pound for pound, to that of bread, must of necessity be chosen. The strong demand for such materials, together with dried vegetables, as supplies for foreign troops which has existed for the past two years is now materially strengthened by the needs of neutral countries and non-combatants and of our own fighting men, and it is clear that this increased demand is destined to continue for years to come at prices well above the cost of production. Consequently, the construction of by-products plants, which has long been a necessity as a means of reducing orchard waste and maintaining fresh fruit values, becomes an even greater necessity in meeting the needs of the world for food.

CONDITIONS DETERMINING THE SORT OF BY-PRODUCT PLANT NEEDED

Since there are, broadly speaking, two general methods of preserving perishable foodstuffs, by sterilizing with heat and sealing or by reducing the moisture content to a point at which growth of bacteria and fungi can not occur, the by-products plant must be either a cannery or an evaporator. If it is to utilize fully all the unmarketable and surplus materials of its district, the cannery must carry on such related activities as the making of jams, jellies, marmalades, preserves, fruit butters, and cider or vinegar, while the evaporating plant may advantageously utilize its waste by manufacturing vinegar therefrom, subsequently employing the pomace as a food for cattle. Consequently, any step toward utilization of low-grade fruit in a community involves first of all a decision as to whether a cannery or an evaporator will best meet the needs of the particular case. A very large number of factors,

some of which are obvious while others are apt to be overlooked by persons unfamiliar with the operation of such plants, need to be very carefully considered in making such a decision, and it may be of some value to briefly review these before going further.

The writer desires to say frankly that his study of conditions in the state compel him to regard the establishment of a cannery, either by an individual or by a co-operative organization, as a very doubtfully profitable undertaking unless the conditions are favorable to a very exceptional degree. This attitude is, I believe, fully justified by the past history of canneries in general, and of co-operative canneries in particular, in the Northwest.

The Report of the Chief of the Office of Markets and Rural Organization for 1915 characterizes the business of the co-operative cannery as a hazardous one, stating that more than 80 per cent of such canneries have been total failures[1]. That office has made a careful survey of the business of 21 representative co-operative canneries in Washington, Oregon, and California, and has brought together an enormous mass of data which may be obtained by those who are considering the establishment of such a cannery upon request made to the Chief, Office of Markets and Rural Organization, U. S. Department of Agriculture, Washington, D. C.

Briefly stated, success in the establishment and operation of a cannery demands ample capital for installing efficient modern equipment and employing well trained and experienced supervisors of the technical processes involved, as well as for the purchase of cans, raw materials, and labor, and for carrying the manufactured product in storage until favorable marketing conditions are obtained. There must be available at moderate prices an ample supply not only of fruits but of vegetables also, in order that overhead charges may be reduced by a long working season at full capacity. Transportation facilities must be good and rates must be favorable, since

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1. Brand, Charles J.—Report of the Chief of the Office of Markets and Rural Organization, Separate from Annual Report Dept. of Agriculture, 1915, pp. 7-8.

the plant will purchase its cans and its fuel at a distance and will have to transport its bulky product to the markets. Fuel and labor must be obtainable at moderate rates. Finally, every cannery has to solve a marketing problem distinct from that of every other similar concern. Canned goods of the better grades are coming to be sold upon the reputation of the maker's name or brand almost to the same degree as are smoking tobaccos or breakfast foods, and the new cannery must be financially strong enough to forego profits while it is establishing a reputation and a market for its goods. Lacking any of these conditions, or possessing them but lacking a manager who combines administrative ability and good salesmanship with unlimited energy, the new cannery is likely to prove a worse than doubtful investment.

Comparatively speaking, the evaporating plant has many advantages over the cannery. The initial cost of building and equipment necessary to handle a given volume of material is much less, the machinery is less costly and depreciates much less rapidly. The employment of a technically trained, high-salaried supervisor is not necessary. Therefore, the fixed charges (interest on investment, depreciation, insurance, supervision) are proportionately lower, and many of the best evaporators of the Eastern apple districts make a profit despite the fact that they dry nothing but apples, hence operate only about 60 days each year. Under the conditions prevailing in Washington the working season could be lengthened to 90 days, and there are few districts in the state in which an evaporator would not have either peaches, berries or prunes, in some quantity, to further lengthen its operating season. While the evaporator is by no means independent of facilities for transportation, it has the enormous advantage that it produces a concentrated product which can be transported far more cheaply than either fresh fruit or canned goods; which requires no outlay for expensive containers, and which can be stored almost indefinitely, under proper conditions, in relatively small space. Finally, the product is one which is readily examined and graded, hence every lot goes on the market at the price to which its quality entitles it, and does not de-

pend upon brand name or previously established reputation for its sale.

What has just been said must not be misinterpreted: the business of evaporation is one which has its hazards, the margin of profit is moderate, and the poorly managed, badly located plant will fail no less certainly than if it were an improperly located, badly managed cannery. But given an assured and adequate supply of fruit of good quality at moderate prices, a modern equipment of efficient, labor-saving machinery, and capable oversight and management, an evaporating plant has more than a fair chance of realizing a reasonable return upon the investment anywhere in the Northwest.

REVIEW OF THE LITERATURE RELATING TO EVAPORATION

While the evaporation of apples and berries has long been an established industry in certain sections of the United States, and the evaporation of prunes, peaches, apricots, and loganberries has in recent years become a business of very considerable magnitude, the literature dealing with the subject of evaporation is surprisingly small in amount. The methods in use today have been gradually developed by practical evaporator operators and have never been subjected to systematic scientific investigation with a view to their improvement and increase in efficiency. Consequently such papers as deal with the subject, while they are for the most part publications of various experiment stations, are confined to descriptions of prevailing methods in use, with very few suggestions for their improvement. Since old methods are continually undergoing modification or being entirely replaced by more efficient ones, many of these descriptions have now little more than historical value, because they apply to machines and processes most of which have become obsolete. This brief review is inserted here in the hope that it may be of service to those desiring to acquaint themselves with the existing literature.

In 1895, Professor L. H. Bailey of Cornell University[1], in a bulletin on the evaporation of raspberries, outlined the history of the evaporator industry in Western New York, briefly described the first small portable evaporators used, and devoted a few paragraphs to steam and kiln driers. The paper is chiefly devoted to a de-

1. Bailey, L. H.—Evaporated Raspberries in Western New York. Bulletin 100, Cornell University Agricultural Exp. Sta., 40 pp. 1895.

tailed description of the then widely used Culver-Cassidy tower or stack evaporator, which has since gone wholly out of use in New York, although it is still employed in a modified form in California. Two years later, Professor U. P. Hedrick of the Oregon Agricultural Experiment Station, in a comprehensive bulletin of that station on the cultivation and drying of prunes[1], devoted some twenty pages to descriptions of six evaporating plants used in the evaporation of prunes. Only two of these, the Allen and the Carson, have survived the test of time and have done so only through extensive modification and improvement. Balmer[2], in a bulletin on prunes, issued by the Washington Station in 1899, has described a number of evaporators, including several not mentioned by Hedrick, but diligent inquiry has failed to discover an operator who is using one of them at the present time.

Alwood[3], in a paper appearing in 1895, described a small steam evaporator devised by himself, which appears to have very little to differentiate it from a number of others put on the market about that time. Alwood's experimental machine turned out a product of excellent quality, but the cost of construction and operation was so high as to prohibit its use commercially, and the author abandoned the work without obtaining any results of practical value[4].

Farmers Bulletin 213, by L. C. Corbett[5], is devoted primarily to the culture of raspberries, but takes up also methods of evaporation. Three types of evaporators, all derived by slight modifications from types generally in use for the evaporation of apples, are rather briefly described. These are the shaft or flue evaporator, identical in general construction and operation with the tower evaporators employed for apples, the cabinet evaporator, and the hop-kiln drier, which is the kiln universally used in the New York apple districts. Some general facts as to construction are given and the relative merits of the different types for use in drying raspberries are briefly discussed, but no estimates of cost of construction or of operation are given.

The only paper dealing in any detail with all phases of the construction and operation of evaporators is that of Gould[6]. The three

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1. Hedrick, U. P.—Prunes in Oregon. Bulletin 45, Oregon Agricultural Exp. Sta., 127 pp. 1897.
2. Balmer, J. A.—Prunes. Bulletin 38, Washington Agricultural Expt. Sta., 44 pp. 1899.
3. Alwood, Wm. B.—Evaporating Apples, Bull. 48, Virginia Agricultural Exp. Sta., 16 pp. 1895.
4. Alwood, Wm. B.—The Utilization of Unmerchantable Apples. Bulletin 57, Virginia Agricultural Exp. Sta., 16 pp. 1895.
5. Corbett, L. C.—Raspberries. U. S. Department of Agriculture Farmers Bulletin 213, 38 pp. 1905.
6. Gould, H. P.—Evaporation of Apples. U. S. Department of Agriculture Farmers Bulletin 291, 38 pp. 1907, re-issued without change, 1915.

types of evaporators just named are described therein in considerably greater detail than in Corbett's paper, especially in the case of the kiln evaporator. In addition, evaporator appliances and machinery, paring machines, slicers, bleachers, heating apparatus, the selection and preparation of fruit for drying, temperatures employed, time for drying, amount of fuel needed, and methods of packing the dry product are among the topics receiving attention.

Other papers dealing with some phase of the industry are those of Warren[1], Brackett[2], Fraser[3], Dosch[4], and Allen[5]. The first named is a very brief popular statement of methods which describes a few small home or family driers, while Brackett's paper is a purely general discussion of drying and canning. Professor Fraser's paper reviews in some detail the development of the dried fruit industry in the various states concerned, and points out the need of scientific study looking toward the improvement of the product. The papers of Dosch and of Allen are concerned with the evaporation of prunes and are devoted to criticisms of incorrect practices rather than to systematic descriptions of drying plants or directions for their operation.

Two recent papers[6,7] from the Oregon Agricultural Experiment Station deal to some extent with the evaporation of fruits, in connection with a general discussion of means of utilizing surplus fruits. The first of these papers devotes four pages to a general outline of the process of evaporation in kiln driers, the second contains plans of a model tunnel evaporator with a discussion of methods of picking, handling, and drying loganberries and a statement of results of experiments with evaporation at various temperatures. Brown and Bradford of the Oregon Station, in a paper on the drying of prunes[8] briefly describe the stack, tunnel and Jory driers. Their

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1. Warren, G. F.—Evaporating as a Home Industry in the United States. Bailey's Cyclopedia of American Agriculture, 4th ed. Vol. 2, pp. 174-177. 1912.
2. Brackett, G. B.—Utilizing Surplus Fruit. Yearbook, Department of Agriculture, 1888, pp. 309-317.
3. Fraser, Samuel—The Dried Fruit Industry in the United States. The Evaporator, Vol. 4, No. 12, pp. 7-14, September, 1912.
4. Dosch, Henry E.—Fruit Evaporation. Fifth Biennial Report Board of Horticulture of Oregon, pp. 440-446. 1898.
5. Allen, R. D.—The Prune and the Methods of Evaporation. Fifth Biennial Report Board of Horticulture of Oregon, pp. 485-493, 1898.
6. Lewis, C. I., and Brown, W. S.—Fruit and Vegetable By-Products. Oregon Agricultural College Extension Service, College Bull. 128, pp. 48. 1914.
7. Lewis, C. I., and Brown, F. R.—Loganberry By-Products. Oregon Agricultural Exp. Sta. Bulletin 117, 32 pp. 1914.
8. Brown, F. R., and Bradford, F. C.—The Drying of Prunes. Biennial Crop Pest and Horticultural Report, Oregon Agricultural Exp. Sta., 1911-1912, pp. 51-58.

paper also discusses methods of dipping and bleaching, temperatures for drying, and cost of the process.

Farrell[1] has described and given full plans for the construction of a small cabinet evaporator devised by himself. The plan combines some features of the older family or cookstove driers with others derived from the tunnel evaporator. The capacity of the plant is 30 to 50 bushels per day when operated continuously, which would make its cost of operation prohibitive under the conditions prevailing in Washington, unless operated by members of the owner's family who would otherwise have no profitable employment.

Brannt's comprehensive treatise on the manufacture of vinegar[2] contains a rather full description, with figures, of two tower evaporators called from their inventors the Alden and the Williams, which have now been entirely replaced, except in certain districts of California, by the more economical kiln evaporator. The description of the kiln evaporator given is quoted bodily from the paper by Gould already cited. Some general statements as to the methods of preparing apples and vegetables for evaporation are given, but the whole account is of a general character and contains little which would be of help to an amateur desiring to enter the business.

A very brief description of a kiln evaporator is given in a publication by the Secretary of the Missouri State Horticultural society[3]. The directions for construction, estimates of material necessary, and suggestions for operation are clear and concise, but the type of building is the cheapest, most flimsy wooden structure possible.

Catchpole[4] has given a general account of the development of the evaporated apple industry of New York, which briefly discusses various types of plants formerly or at present used, outlines the methods employed with some consideration of equipment, and devotes a few paragraphs to the marketing of the product.

Wickson's work on "California Fruits[5]" devotes a section to an excellent and somewhat detailed presentation of the methods of sun drying in the open air employed in California, with discussion of equipment used and of the treatment given each of the more important fruits. Directions for constructing and operating a machine

1. Farrell, J.—Apple Drying. Journal of the Board of Agriculture, Victoria, Australia, 16:196-211. 1916.

2. Brannt, Wm. T.—A Practical Treatise on the Manufacture of Vinegar, 3rd edition, Philadelphia, 1914, pp. 465-486.

3. Goodman, L. A.—Commercial Fruit Evaporators. Circ. Inform. 14, Univ. Mo. Agric. Expt. Sta. 1903.

4. Catchpole, E. W.—The Evaporated Fruit Industry in New York State, in The Fruit Industry in New York State. N. Y. State Dept. of Agric. Bulletin 79, Part I, 937-953. 1916.

5. Wickson, E. J.—The California Fruits and How to Grow Them, 5th edition. Pacific Rural Press, San Francisco, pp. 528-546, 1910.

evaporator which is essentially a somewhat modified prune drier in type, are also given. Many helpful suggestions as to the making of trays, the sulphuring of fruit, and the handling of fruit in open-air sun drying as practiced in South Australia are given in an article by Lewis[1] and fuller directions covering all phases of sun drying as practiced in the vicinity of Adelaide, South Australia, have been given by Quinn,[2] while an anonymous writer has described the methods employed in sun drying peaches in Chili[3]. Caldwell[4], in a bulletin of this station, has described methods of sun drying, either in the open air or in a glass-covered "solar drier" which materially hastens the drying process while it also protects the fruit from dust and insects. This publication also describes several small driers which can be very cheaply constructed by the individual grower and which have sufficient capacity to handle the surplus fruit and vegetables of the home orchard and garden.

The drying of vegetables has hitherto received so little attention in English-speaking countries that there is practically no literature in English dealing with the subject. The methods in use in Germany, where the dessication of potatoes for use as food or for stock purposes has long been a well established industry, are well summarized by Marr[5] and Meyer[6 7], but the drying of potatoes is for the most part carried on in large commercial installations and in connection with the manufacture of potato starch or of alcohol, or with equipment designed for drying only potatoes or potatoes and beet refuse for feeding purposes rather than with apparatus designed for the drying of a wide variety of vegetables and fruits, and the literature is chiefly devoted to commercial practices in highly spe-

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1. Lewis, W. R.—Fruit Drying. Journal of Agriculture of South Australia 19:667-660, 1916.

2. Quinn, Geo.—Fruit Drying for Beginners. Journal of Agriculture of South Australia. 11:5454-464, 1911. Also issued with same title as Bulletin 31 of the Dept. of Agriculture of South Australia.

3. Anon—L'industrie de la dessication des Peches au Chile. Bulletin mensuel de l'office des Rensiegn Agricoles. 6:707-710, 1911. Abstract in Bulletin Bureau of Agric. Intell. and Plant Diseases. 2:1748-1749, 1911.

4. Caldwell, J. S.—The Home Drying of Fruits and Vegetables. Washington Agricultural Experiment Station, Extension Bulletin 27, 1917.

5. Marr, G. H.—Das Trocknen und die Trockner, 2nd Ed. Berlin, 1914.

6. Meyer, D.—Die Kunstliche Trocknung der wasser-reichen Futtermittel. Leipzig, 1915.

7. Meyer, D.—Handbuch der Futtermittel und Getriede-trocknung. Janecke, Leipzig, 1912.

cialized plants. Papers by Martens[1], Valvassori[2], and Malpeaux[3] describe the methods in use on the smaller farms in drying fruits, potatoes, and other root crops and vegetables in Germany, Italy, and France, but the industry as conducted on the small scale has been developed without the aid of any exhaustive scientific study of drying methods and there is consequently little in the literature which would be of direct value under American conditions. The somewhat detailed work of Forlani[4] on the conservation of fruit, fungi, truffles, and vegetables, published in Italian, is not yet generally available to students in this country.

As regards chemical studies of the composition of evaporated fruits or of the changes in composition undergone in the process of drying, a diligent search of the literature reveals very little. In 1886, Edgar Richards[5], working in the Bureau of Chemistry of the U. S. Department of Agriculture, made comprehensive analyses of entire fresh fruits and of peeled and cored fruits, before and after drying, on 17 varieties of apples. The results show the character and extent of the slight changes undergone in the course of the drying process, and the methods employed in drying are very briefly described. In 1899, C. A. Browne, Jr., of the Pennsylvania Agricultural Experiment Station, published a report of rather extensive studies of the chemistry of the apple and apple products[6]. Five pages of this paper are devoted to discussions of chemical composition of evaporated apples in comparison with fresh fruits; to the effects of sulphuring, and to relative yield of dry product from different varieties of apples. Lastly, Brannt, in the work already cited, gives composition before and after evaporation for Baldwin apples.

Studies of the chemical composition of fresh and dried prunes have been carried on at the Oregon Station by G. W. Shaw. In a publication by Hedrick, already cited, some eight pages are devoted to reports of Shaw's analyses of a number of samples of Italian

1. Martens, E.—Dorrbuchlein fur Hausholt und Kleinbetrieb, Anleitung zur Trocknen von Obst und Gemuse. Berlin, 1914.

2. Valvassori, V.—The Conversion of Fruits and Vegetables into Dried Products. Monthly Bulletin Agric. Intell. & Plant Diseases, 7:1353-1355, 1916.

3. Malpeaux, L.—Agricultural Dessicating Installations. Monthly Bulletin Agric. Intell. and Plant Diseases. 7:270-273, 1916. Abstracted from La Vie Agricole 6:1-8, 1916.

4. Forlani, R.—Conservazione delle Frutta, die Funghi, dei Tartufi, e degli Ortaggi. Licinio Cappelli, Rocca San Casciano, Italy. pp. 207. 1915.

5. Richards, Edgar—Analyses of Apples. Report Com. Agric for 1886, Washington, D. C., 1887, pp. 350-355.

6. Browne, C. A., Jr.—A Chemical Study of the Apple and Its Products. Penn. Dept. Agric. Bull. 58, 46 pp. 1899.

and Silver prunes, fresh and dried, and a later publication[1] gave results of a more extensive series of analyses of a number of varieties. At the California Agricultural Experiment Station, extensive investigations of the chemical composition of prunes, peaches, and apricots were made by G. E. Colby[2] and are reported in the Annual Reports of that Station for the years 1891-94, while methods and effacts of sulphuring are briefly discussed by E. W. Hilgard in a publication of the same station[3].

A considerable number of papers dealing in more or less general and popular fashion with some of the various phases of the subject of fruit evaporation are scattered through the files of the horticultural journals. Mention of these is omitted, since the purpose of this review is not to bring together a complete bibliography of evaporation, but to notice such papers as will be at once accessible and valuable. It will be obvious to the reader that of these, those of Gould, Corbett, and Lewis and his co-workers are the most recent, and therefore the only ones which may be said to deal with methods actually in general use.

Of the present paper it may be said that it has been the author's purpose to bring together from the literature all the existing data of value in regard to evaporators and their operation; to supplement this by including the results of personal investigation and inquiry, and to prepare somewhat more detailed plans for construction and instructions for equipment and operation of evaporators suitable for use in the Northwest than are at present to be found in print.

TYPES OF EVAPORATORS

In what follows it is the author's purpose to describe in some detail those types of evaporating plants which have been subjected to the thorough test of long continued general use, and proven thereby to be efficient and profitable when operated upon a commercial scale. Consequently, no attempt is made to include such evaporating devices as have at some time in the past been in more or less extended use but have since been gen-

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1. Shaw, G. W.—The Oregon Prune; Its Composition, Food Value, Soil Draught, Oregon Agric. Exp. Sta. Bull. 61, 18 pp. 1900.

2. Colby, G. E.—Analyses of Fruit and Vegetable Products. Report Agric. Exp. Sta. Univ. of Calif. for 1891-92, pp. 91-116; same for 1892-94, pp. 257-274; also Bulletins 93, 97, and 101 of that Station.

3. Hilgard, E. W.—The Sulphuring of Fruits. Report Agric. Exp. Sta. Univ. of Calif., 1890, pp. 131-133; also Bulletin 86 of that station.

erally discarded[1]. Nor is any mention made of two or three machines, essentially new in type, which are just now attracting some attention in the Northwest, for the reason that none of these can be said to have passed the experimental stage, and it yet remains to be seen whether they can be constructed and operated upon a commercial scale with any assurance of a reasonable profit. Also, no description is given of any of the numerous "family dryers" or "family evaporators" of small capacity, intended to be operated over a kitchen stove or small heater and to furnish a means of drying the winter supply of fruit for the family, as such dryers are described in Extension Bulletin 27 of this Station.

In the descriptions of evaporator buildings and equipment which follow, no attempt has been made to draw up rigid detailed specifications covering all the details of construction. The intention is to present general schemes for the construction of buildings in which the general arrangement shall be as convenient and as well adapted to the purpose as possible, hence the plans are drawn from buildings operated by practical evaporator men of long and wide experience in the business, and commended by them as embodying the best possible features. Local conditions must determine the materials to be used in construction, the extent to which power machinery shall take the place of hand labor, the type of heating equipment to be used, and many other details. The person entrusted with the construction of the building and the installation of the equipment must have had sufficient experience in construction and in the making or the interpreting of plans to be able to work out such modifications of the generalized plans as will adapt them to the needs of the particular case. It is believed that the descriptions are sufficiently detailed, when studied in connection with the accompanying sketches and the estimates of material necessary, to enable a workman of ordinary experience to do this.

1. The reader who is interested in the history of evaporation in the Northwest will find a large number of machines of the class here mentioned briefly described in "Prunes in Oregon," by U. P. Hedrick, Bulletin 45, Oregon Agricultural Experiment Station, 1897, and in "Prunes," by J. A. Balmer, Bulletin 38, Washington Agricultural Experiment Station, 1899.

The Types of Evaporators Recommended. In the following pages will be found descriptions of three types of evaporators. It may be said briefly of these that a choice of the type to be constructed should be determined by the nature of the material to be handled. If the district is one devoted practically wholly to apples, the kiln evaporator is the most economical and efficient type to employ, since it will dry apples or such vegetables as potatoes, carrots, beets, cabbage, or onions perfectly and will, with proper precautions, give an acceptable product with berries, peaches, or apricots. But if the district be one devoted to general fruit growing and berries, cherries, peaches, apricots, and prunes make up a large part of the material to be handled by the plant, a tunnel or an "all purpose" evaporator should be built, since either of these plants, without alteration of the equipment, will dry any fruit or vegetable which can be dried and the slightly greater initial cost of the plant will be offset by the longer working season made possible by the presence of a variety of fruits.

Sources of Information. It is impossible to acknowledge in detail the writer's obligations to those who have supplied material used in the preparation of this bulletin. More than one hundred operators of evaporators in New York have not only permitted personal inspection of their plants, but have also supplied detailed information as to every phase of the work. Similar courtesies have been shown by a large number of dealers in evaporated fruits and manufacturers of evaporator machinery and equipment. Detailed information of like character has also been supplied by the owners or managers of plants in Oregon and Washington, visited in the course of this study. The writer is also under obligation to a large number of workers in the Experiment Stations of the more important fruit growing states, who have cheerfully collected and furnished such information as has been asked for. Lastly, free use has been made of every available source of published information upon the whole subject of the production and marketing of evaporated products.

THE KILN EVAPORATOR

The kiln evaporator first came into use in the United States about 25 years ago, when it began to be used in the New York berry districts for the drying of raspberries. At that time, the evaporation of apples was carried on entirely in tower or stack evaporators. The large capacity, cheap construction and operation, and more uniform quality of the output of the kiln, with the increased opportunity given for the use of labor-saving machinery, gradually led to its general use for drying apples, and it has now completely displaced the tower and stack evaporators in New York, Pennsylvania, Michigan, Illinois, and Arkansas, and practically the entire commercial output of evaporated fruit, except that produced upon the Pacific Slope, is now made upon kiln evaporators.

In its essential features the actual drying room of the kiln evaporator presents little that will be wholly new to those familiar with the construction of the hop kilns once so common in certain parts of the state. The drying unit is two stories in height and in the smallest plants usually 20, much more rarely 18 or 22 feet square. In larger plants the building is divided by walls continuous from ground to roof into a single or double row of units of this size, each such unit constituting a kiln which can be operated independently of the others. The ground floor is usually 10 or 11 feet in height and contains the stoves or heating furnaces, one for each kiln, with space for the storage of fuel. The second floor is usually only sufficiently high at the eaves to permit a man to stand erect, and the ceiling is generally nailed to the lower side of the rafters, this forming an inverted hopper or trough which has a ventilating tower at its apex. The floor is made of narrow slats laid with an interval of one-fourth or three-eighths inch between them, and the fruit to be dried is spread in a uniform layer of four to six inches in depth upon this floor. For the greater utilization and more uniform distribution of the heat supplied by the furnace, the pipe collar is usually fitted with a T joint, or the furnace may have two openings for pipe, and two lines of pipe are carried around the room one or more

times, at a distance of about two feet from floor and walls, before passing into the flue.

Such a kiln will require 18 to 24 hours to dry a charge of sliced apples spread to a depth of five or six inches. As regards capacity, a 20x20 kiln is universally called a hundred-bushel drier throughout New York, as is it is reckoned that eight square feet of kiln floor are necessary to dry the slices made from one hundred pounds of apples. The actual daily working capacity for a kiln of this size varies from 5000 pounds to 4500 or less by reason of atmospheric conditions, peculiarities in the construction of the building, the varying efficiency of the furnaces employed, or the care employed in spreading and turning the drying fruit.

When peaches or apricots are to be dried, they are spread upon the kiln floor to a depth of 1½ to 2 inches, care being taken to spread the halved fruits with the stone cavity uppermost in so far as possible to avoid loss of juice. When raspberries, loganberries, or blackberries are to be dried, the kiln floor is covered with burlap or sheeting, precisely as is the custom in preparing a kiln floor for drying hops; the berries are spread in a layer not more than two inches deep, and are left undisturbed until sufficiently dry to stir without crushing. The loss in capacity due to the thinner spreading of these fruits is largely compensated by the quicker drying which occurs. While the drying of vegetables had not hitherto been carried on to any extent. the strong demand for easily transported supplies for the use of the European armies led, two years ago, to the rather general use of kiln evaporators, particularly in the New York evaporator district, for the drying of potatoes, carrots, beets, onions, and cabbage, and many thousand tons of these vegetables were successfully dried for export.

Construction of the Building. The building for an evaporator should be of fireproof construction. Wooden buildings are to be strongly advised against, not only because of the very great danger of fire, but also because there is considerable loss of heat by radiation through wooden walls, which may make it impossible to control the temperature during unfavorable

weather. The ideal evaporator building is one which is practically airtight except at air inlets and ventilators, which gives perfect control of temperature and utilization of fuel, and which has fire risk, depreciation, and repairs cut to a minimum by the use of a permanent type of construction. These conditions are impossible of attainment in a wooden building. The work of preparing the fruit for drying can, in case of necessity, be carried on in any building which can be made into a light, comfortable, sanitary workroom, but the added convenience of having everything beneath one roof and in a building especially designed for the purpose will repay the increased cost.

The materials to be used in building will of course depend upon location and local conditions. Building tile makes an ideal building, since the dead air space within the tile materially reduces loss of heat by radiation, but the cost of tile or of brick will be somewhat high in many localities. Where stone is available in the immediate locality, it will be cheaper than any other fire proof material. Concrete or concrete blocks will cost much less than tile or brick, but perhaps the least expensive method of construction would be to use metal lath and plaster on both inside and outside walls on a wooden frame, with steel girders and metal roof. Old railroad rails, if obtainable, may be used as joists, by the use of wooden strips upon the upper surface to which floors may be nailed. Such a building, if supplied with steel doors, has literally nothing which can be burned except the kiln floors, and if the doors are kept closed, fire can not spread from the kilns to the workroom.

The cost of construction of a given building will, of course, vary considerably with location, railway facilities, local labor costs, and current prices of materials. In order to supply data from which probable costs can be worked out as accurately as possible by the individual builder, detailed bills of materials have been made out for several of the buildings described herein, and these have been submitted to architects in various parts of Washington for estimates as to cost of materials and of construction. Such bills of materials and cost esti-

mates will be found on a succeeding page; it is hoped that they may furnish a basis from which a prospective builder in any given section of the state may reach a fairly accurate estimate of the probable cost of the plant he desires to construct.

The plans which follow are the best obtainable after close study of various types of construction. They are intended to serve as suggestions which may be modified to suit the needs of the individual builder. Thus the two-kiln plant can be readily expanded into a three-kiln plant, that having four kilns into one having five or six. The plans contemplate the use of some source of power for running parers, bleachers, and slicers, since no more serious mistake than the installation of hand power machines in his plant could very well be made by any one starting into evaporation as a business. The labor of turning the hand driven parer is considerable, the women operators become fatigued, and a smaller output per machine of poorly pared, imperfectly cored fruit, requiring more work at the hands of the trimmers, is the result. The task of slicing the fruit with the best hand-driven slicer available is a laborious and time-consuming one. Moreover, the daily transfer by hand of 200 bushels of fruit from paring table to bleacher and from bleacher to slicer, with a climb to the second floor with each load included, is a task which few able bodied men will care to continue day after day. A gasoline engine such as is everywhere used for spraying, or the employment of motors where electric current is available, will eliminate this hand labor; the cost of hand and power driven machines is practically equal, while the saving in wages in two seasons will pay for the shafting, belting, and labor necessary to construct conveyors.

It is assumed that where power is employed, a gasoline engine placed somewhere outside the building will be used. Hence no special provision of space has been made in any of the plans for an engine placed inside the walls.

Two-Kiln Evaporator—Figures I and II show plans of a two-kiln evaporator with 18x20-foot kilns, having an average daily capacity of 8500 pounds of fresh fruit or a seasonal capacity

for a 60-day evaporating season of approximately 250 tons if no peels and cores are dried. Since this amount of apples at least will be available in ordinary seasons in any locality where the construction of a commercial evaporator is being seriously considered, plans for smaller plants are not included here. Those desiring suggestions as to the building of smaller plants suited to the needs of the small ranch will find such plans in Extension Bulletin 27 of this Station. It must be emphasized, however, that the operation of smaller plants by the employment of hired labor, under conditions prevailing in Washington, can scarcely be commercially profitable, while the two-kiln plant will yield a comparatively narrow margin of profit if any considerable portion of the labor employed must be paid for at current rates.

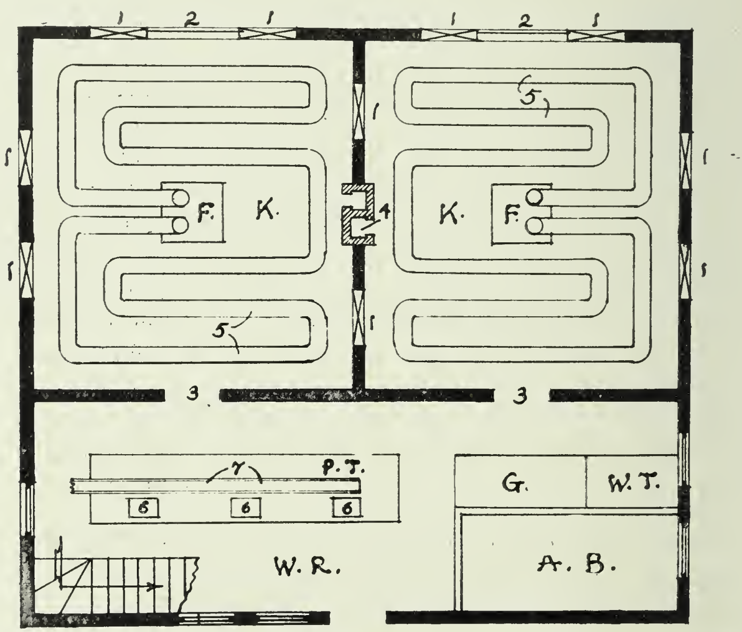


Fig. I. Two-kiln evaporator, ground-floor plan. K, kilns, each 18x20 feet. W.R., work room, 12x36 feet. A.B., apple bin. W.T., washing tank. G., grader. P.T., paring table. F., furnace. 1,1, ventilators, 3x1½ feet. 2, fuel doors of kilns. 3, doors from work room. 4, chimney of furnaces. 5, piping of furnace. 6, parers. 7, apple conveyor on paring table.

In the following description, details as to construction of a number of essential parts of the equipment, for example, paring tables, apple and waste conveyors, etc., are omitted. These are fully described and figured in the section on "Model Four-kiln Evaporator." The construction and arrangement are essentially the same in the two cases.

Since the plant will be employed primarily for the drying of apples, such references to operation as are made are concerned with the handling of apples. A full discussion of the handling of other fruits and also vegetables will be found in a later section.

The building shown in the plans is 36x32 feet in size, and 16½ feet in height at the eaves. The first story is 10 feet in height to the floor, and is divided into two furnace rooms, each 18x20, and a paring room 12x36 feet. The furnace rooms have considerable space available for the storage of fuel. The

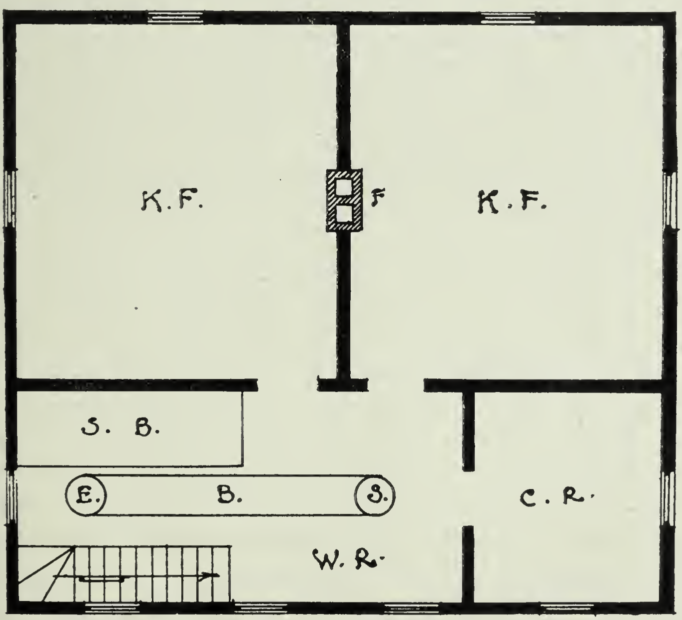


Fig. II. Two-kiln evaporator, second-floor plan. K.F., kiln floors. W.R., work room. C.R., curing room. S.B., storage bin. E., elevator. B., bleacher. S., slicer. F., chimney of furnaces.

furnace, arrangement of piping, etc., is subsequently discussed in detail under the head "Heating Apparatus." The most important feature of the construction of the furnace room is that adequate provision for inlet of air be made. The plans here given provide two air inlets on each side of every kiln, each 3x1½ feet, placed six feet apart and at a distance of six inches above the floor of the kiln. When kilns stand in series, the wall between adjacent kilns has these openings just as do the outside walls, and upon the side on which the paring room adjoins the kilns, openings in the outer wall lead beneath the paring room floor to the openings in the kiln. Such an arrangement secures perfect control of the air movement irrespective of direction of wind. Sliding iron doors running in grooves permit opening or closing of the air inlets to any desired degree.

Each of the furnace rooms should have a sheet iron door opening to the outside, in order to permit the unloading of fuel directly into the kiln. This door may be centrally placed in the outer wall, as indicated in the plans, and need not be more than five feet high. It should be four feet in width to facilitate easy handling of wood. Most important of all, it should be fitted with a good substantial lock and the key should be in the possession of the furnace man, in order that careless or irresponsible people may not stop the drying process by leaving the door open.

The floor of the paring room should be of a good quality of matched flooring and should be carefully laid in order to facilitate cleaning. It should be elevated sufficiently above the ground to permit free passage of air from the inlets in the outer wall to those in the walls of the kilns, as shown in the plans of side elevation of the four-kiln evaporator. One end of the paring room is occupied by a storage bin 12x6 feet, which may be given a capacity of 14 to 15 tons of apples by carrying its walls up to the ceiling. The storage bin is filled from outside. As apples are used they are drawn through a sliding door directly into a washing tank. If no power equipment is available, one man washes off adhering dirt, throws out overripe and rotten apples, runs the washed apples through the

grader if it is desired to separate the fruit into several sizes prior to peeling, keeps the peelers supplied with apples, and removes peelings as they accumulate. One man can easily do this while attending to the fires in the kilns, if the arrangement suggested is followed. If power is available, a belt conveyor which carries the washed apples to a bin on the second floor, from which a system of chutes distribute them to the parers as needed, should be installed. This arrangement, which is fully described on a later page, enables one man to prepare enough apples for a day's run in a little more than an hour, leaving the remainder of the day free for other work.

The paring table should be constructed as described on page 40. It is lighted by two large windows and the parers sit beside these windows with the light falling over their shoulders. The peeled fruit rolls across the table from the peelers to the trimmers, who sit opposite. The trimmers remove bits of parings, bruised spots and other imperfections, and throw the trimmed fruit on an endless belt conveyor, shown in the center of the paring table and fully described in a later section, which carries the fruit into the elevator and thus to the bleacher, as the fruit is bleached before, not after, it has been sliced. In the absence of a source of power, the trimmed fruit must be dropped into boxes which are carried to the bleacher by hand as they become filled. In no case should fruit be allowed to lie any length of time after peeling before placing in the bleacher, or darkening will certainly occur.

Several types of bleachers are in use and the next step in the process will depend upon the particular type employed. The type which is most widely used consists of a long, tight box, 18 inches to 2 feet in width and with a length of 2 to 4 feet per ton of daily capacity, or 24 to 40 feet for a four-kiln plant. The apples are carried by the conveyor into one end of the bleaching box and fall upon an endless slat and chain belt which extends the length of the bleacher. By means of a worm gear, this belt is made to move very slowly, so that 30 to 40 minutes are required for fruit to pass through the box and drop at the opposite end into a storage bin or directly into the hopper of the slicer. Sulphur is burned in a heavy iron pot

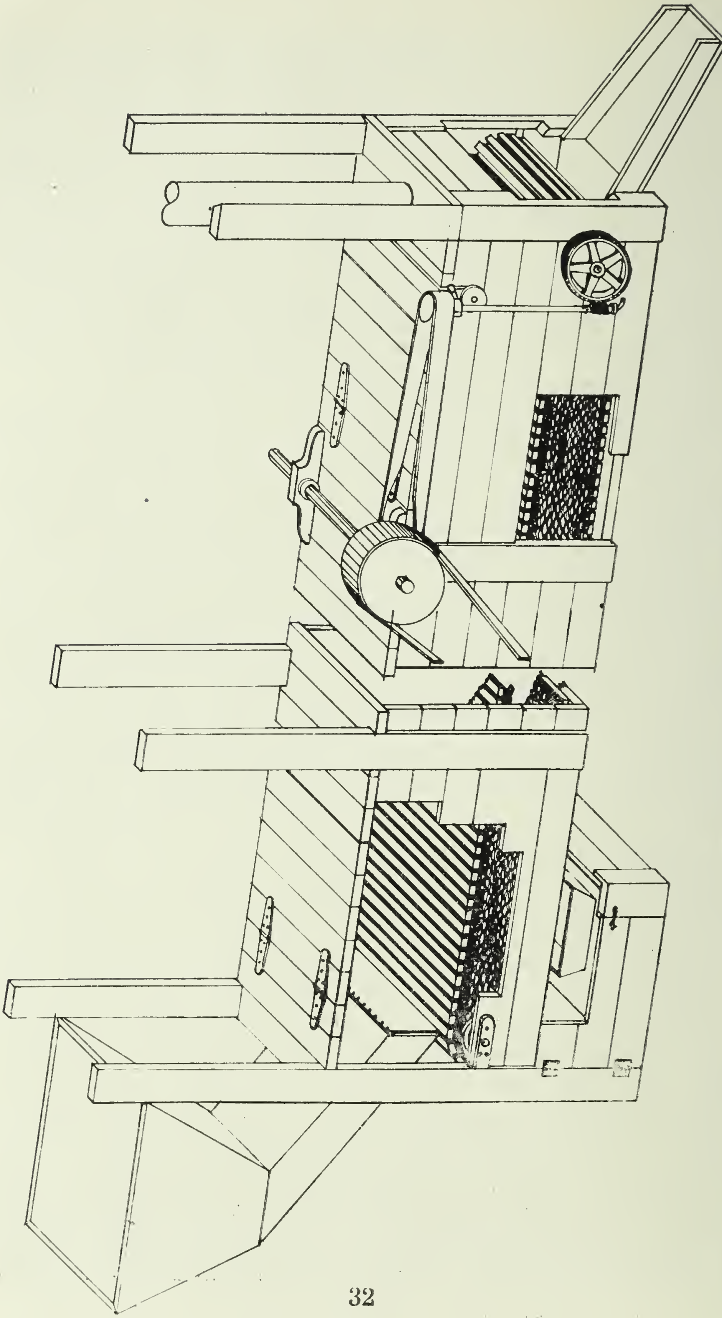


Fig. III. Power bleacher.

or other suitable vessel placed just outside and below the apple inlet, and at the opposite end a small pipe conveys the fumes into the flue. Such bleachers are sold complete by a number of firms, but it is a matter of economy to purchase only the metal parts, since an intelligent carpenter can construct the box and set the machine up ready to run with the aid of the diagram, Fig. III.

In case the plant does not have a source of power, another type of bleacher must be employed. One very common type consists simply of a long box, high and wide enough to receive an ordinary apple box, and sufficiently long to accommodate six to ten such boxes placed end to end. Tightly fitting doors are provided at the ends, and a track along which boxes may slide is made by spiking two 2x4 scantlings on edge to the floor of the box. Sulphur is burned in a pan placed between the tracks at one end, and the fumes are carried off at the opposite end by a pipe, which may be connected with the flue from the furnace. As apples are pared, they are placed in boxes, and as a box becomes filled it is pushed in at one end of the bleacher, moving those already there onward toward the opposite end, where they are withdrawn when sufficiently bleached.

Whatever the type of bleacher employed, it can not be too strongly emphasized that the piping must be carefully done in order that the fumes may not escape into the room. They are intensely irritating to the eyes and throat, and they attack metal so vigorously that when allowed to escape at the level of a shingled roof the nails may be absolutely destroyed in the course of two or three seasons. Therefore, terra cotta pipe, carefully cemented at the joints, or heavy cast-iron pipe (called by plumbers soil pipe) with the the joints set in white lead, should be used, and it should be connected with one of the kiln flues in order to carry the fumes well above the roof. If iron pipe is used, its term of service will be materially increased by flowing white lead paint repeatedly through it at intervals of a few hours, so that the inner surface gets a good heavy coating, and allowing this to become dry before the pipe is put into place.

When taken from the bleacher the fruit should be sliced at once. There are several hand-operated slicers on the market, but the work with the best of them is slow and laborious and requires the time of two men. A power slicer costs very little more, does more and better work in a given time, is automatic in action if a power bleacher delivering into the hopper of the slicer is used, and requires one man only if there is no power bleacher and apples must be fed from barrels or boxes. Consequently a power slicer will save its cost in labor in two seasons.

From the slicer the apple rings fall into boxes or barrels standing on trucks, and are transferred to the kiln floor. Here they are spread as uniformly as possible, usually by means of a wooden rake, to a depth of four to six inches, and are left undisturbed until drying at the surface has made the slices tough enough to permit stirring without injury, which usually requires four or five hours. They are then thoroughly stirred by means of wooden rakes and shovels. This stirring is repeated, at first at intervals of two hours, then more frequently, until the fruit receives three or four thorough stirrings in its last two hours on the kiln floor.

When dry the fruit is transferred from the kiln floor to the storing or curing rooms, where it is piled up to a depth of a foot or more to undergo a slow after-curing process prior to being packed.

The roof of the building is so constructed that the apex or ridgepole is directly over the middle of the row of kilns. The ventilating shaft occupies the apex of the roof, extends the entire length of the building, and should be three feet in width and at least four feet in height. A rather widely used type of ventilator is shown in Fig. IV. Its distinctive feature is the fact that it is double walled, the outer walls having no connection with the inner and being placed at a distance of 12 to 16 inches from them. These outer walls are not covered by the roof of the ventilator, but are boarded solidly except for a space of 14 inches in width at the bottom, which is left open for the entire length. The inner walls are boarded up solidly from the bottom for a distance of three feet, leaving a space a foot in width just beneath the ventilator roof, through which

the warm air escapes from the kilns. The outer wall thus has an opening at the bottom through which currents of cold air moving along the roof of the building may enter the space between the walls, passing up between them and assisting in carrying off the warm moist air escaping at the top of the

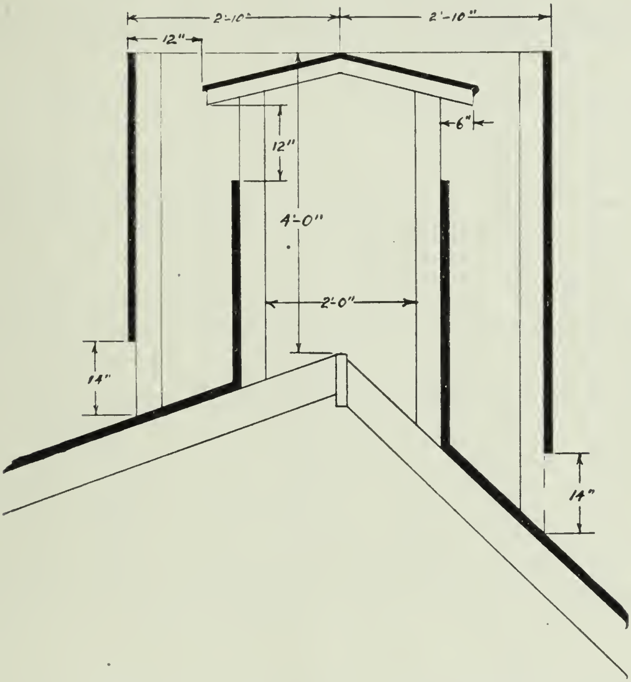


Fig. IV. Details of construction of double-walled ventilator. Warm air escapes from the shaft through the continuous opening 12 inches in width at the top of the inner wall; the opening at the bottom of the outer wall permits cold air to enter and pass up between the walls, assisting the draft, while the upper portion of the outer wall keeps snow or rain from blowing into the shaft.

shaft. The outer wall makes it impossible for the wind to blow directly into the opening in the inner wall, which would interfere with the escape of the warm air, and also keeps rain or snow from driving into the shaft. While such ventilators are said to work well, the fact that they can not be opened and closed with varying atmospheric conditions makes them less efficient than a second type, in which the side walls of the

ventilator are made in sections exactly like the ordinary window shutter, the boards of which the shutters are built being three or four inches wide. By means of ropes attached to the shutters and passing over pulleys, the individual shutter can be opened or closed at will. Such an arrangement permits perfect control of the draft, without which it is impossible to secure uniform results.

Model Four-Kiln Evaporator. Figures V to X give plans for an evaporator having four 20x20 foot kilns with an approximate capacity of ten tons of apples per day. Many features of the construction and equipment are essentially identical with those of the two-kiln plant just described and will be clear without further explanation.

In a plant of this or larger size it would be a fundamental and well nigh ruinous mistake to install anything else than a complete outfit of power machinery. With power driven parers, six girls or women will prepare at least as much fruit as eight women using hand peelers, without the fatigue and consequent careless and imperfect work which occurs when machines are run by hand. With conveyor, bleacher, and slicer driven by power, one man can look after the furnaces and keep the peelers' table supplied with apples and clear of refuse, while a second man can take care of the fruit at the slicer and

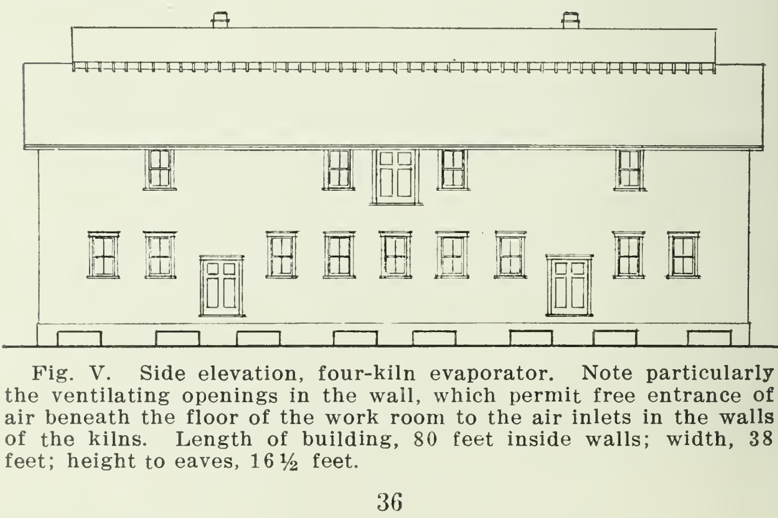


Fig. V. Side elevation, four-kiln evaporator. Note particularly the ventilating openings in the wall, which permit free entrance of air beneath the floor of the work room to the air inlets in the walls of the kilns. Length of building, 80 feet inside walls; width, 38 feet; height to eaves, 16½ feet.

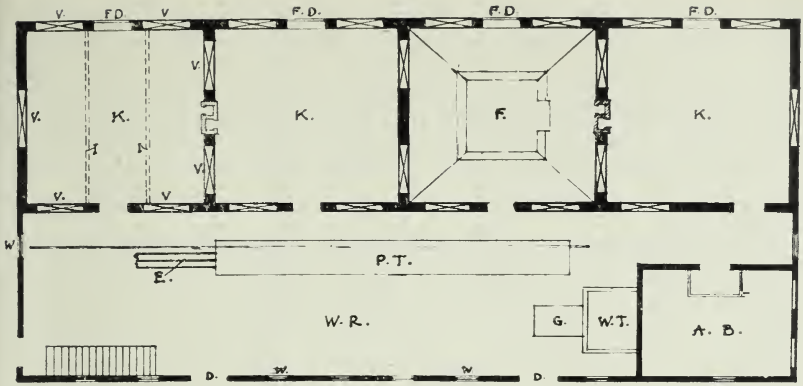


Fig. VI. Four kiln evaporator, ground-floor plan. K.K., kilns, each 20x20 feet. W.R., work room, 80x18 feet. A.B., apple bin, 12x15 feet. W.T., washing tank. G., grader. P.T., paring table. E., conveyors for apples and waste. V., ventilators, 5x1½ feet. F.D., fuel doors to kilns. I., I-beams supporting kiln floors. F., furnace with jacket-and-hopper construction. W., windows. D., doors.

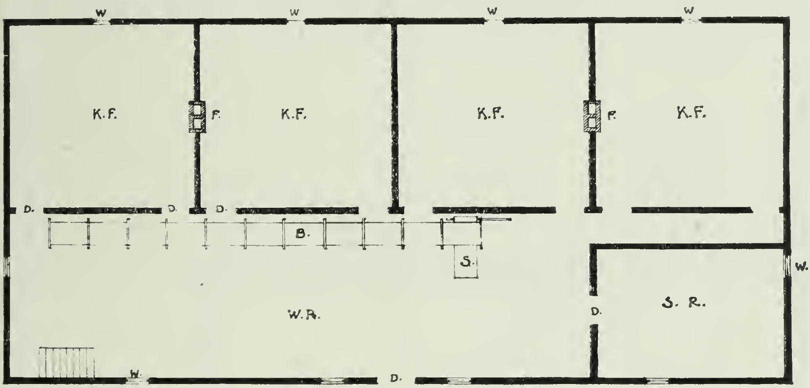


Fig. VII. Four-kiln evaporator, second-story plan. K.F., kiln floors. F., flues from furnaces. W.R., work room. S.R., storage bin. B., bleacher. S., Slicer. D., doors. W., windows.

on the kilns. Were the fruit to be moved and sliced by hand, two additional men or a man and a strong boy would be needed. Consequently, complete power equipment easily saves the wages of six to ten hands in a plant of this size, and will pay for itself in two seasons.

In the plan here given, the apples are delivered from the

wagons to the storage bin, which is 12x15 feet in size. If it is desired to keep varieties such as Ben Davis, Winesap, and Spitzenburg, which make white fruit, separate from the other varieties which make a darker product, which is highly advisable, this bin may be divided into two or more compartments, in which case both the outer receiving door and the door to the discharging chute would be built in sections opening separately for each bin. From the bins, sliding doors open into a discharging chute through which the apples are run directly into a washing tank. From this point there are two possibilities. One man may wash the apples, transfer them to the grader if it is desired to work up large and small apples separately, and carry the fruit from the grader to the tables, or a conveyor may be rigged to carry the apples fom the washing tank to the hopper of the grader, while a second conveyor, placed closely against the wall out of the way, receives the fruit and carries it to a conveniently located bin on the second floor. From this bin a series of chutes pass through the floor and descend to the paring table, each ending in a sliding door

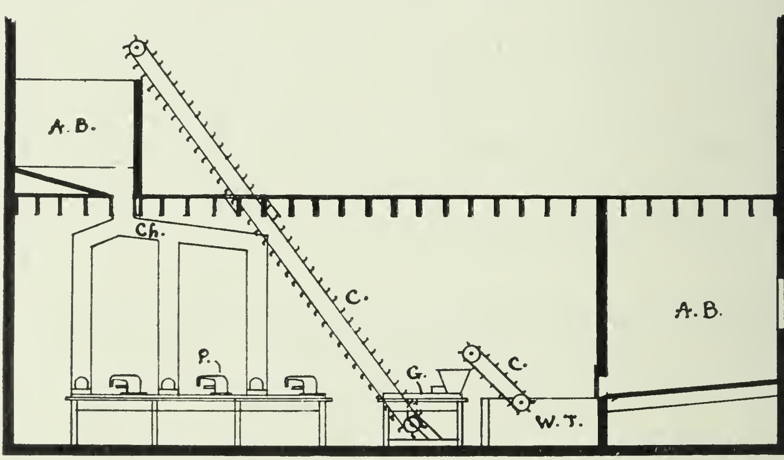


Fig. VIII. Sectional view of evaporator from side, showing belt conveyor from grader to storage bin and chutes from bin to paring table. A.B., apple bin with elevated floor and sliding door delivering into W.T., washing tank. C., conveyor lifting apples from washing tank into hopper of G., grader. C. a second conveyor receiving apples from grader and carrying them to A.B., apple bin on second floor. Ch., chutes from second-floor bin to paring table. P., parers.

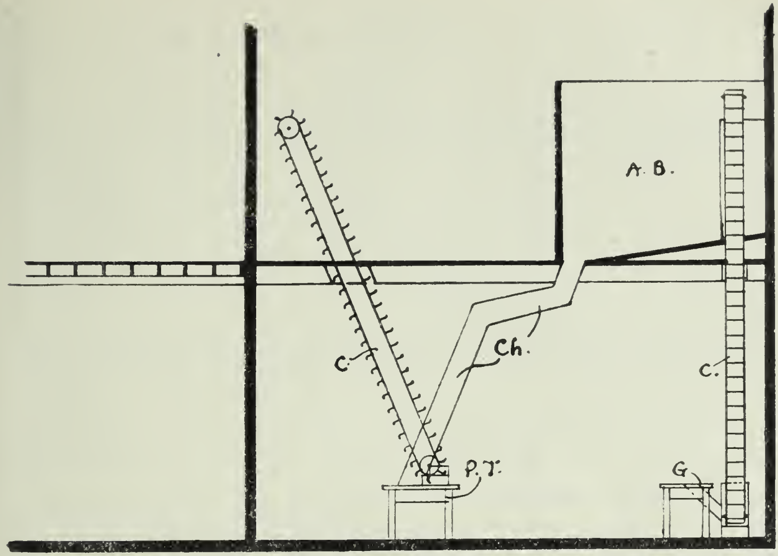


Fig. IX. Sectional end view of evaporator, showing G., grader; C., conveyor; A.B., apple bin with floor inclined to mouth of Ch., chute to P.T., paring table. C., conveyor from paring table to bleacher.

which opens into a box placed beside the parer. With this arrangement, one man can, in a couple of hours, wash and grade enough apples for a day's run and is then free for other work. Since the floor of the bin has a slight inclination toward the chute, the apples pass by gravity from the bin into the chutes, keeping them filled so long as there are apples in the bin, and the parers have only to open the sliding doors for a moment to fill their apple boxes as these become empty. This arrangement is not shown in the floor plans, since it would make the drawings rather complicated, but it is diagrammatically represented in Figs. VIII and IX. The small apples are collected from the grader into boxes or barrels, and are worked up separately when a sufficient quantity has been collected.

The shafting which drives parers, conveyors, and grader is suspended from the joists, and 12 inches below them, so as not to interfere with free movement around the work table. The

apple waste conveyor is six inches wide, and runs in the bottom of a trough seven inches wide and four inches deep, raised six inches above the top of the table, as shown in Fig. X. This elevation of the apple conveyor above the table has two advantages, the peels and cores do not fall into it as would be the case if it ran at the level of the table, also, apples upon it are visible from any part of the room, and it is impossible for a trimmer to do careless work without being detected. The top of the table is slightly inclined—a drop of 1 inch in 3½ feet is sufficient—toward the side at which the trimmers sit, which is faced with a 1x2 strip projecting three-fourths of an inch above the edge. The pared apples drop from the forks of the machines and roll down the slight incline, beneath the conveyor, to the opposite side, where they are arrested by the edging strip. When trimmed, a mere turn of the trimmer's hand deposits the apple on the conveyor. The conveyor for waste is placed below the table, beneath and slightly to the inner side of the paring machines, and an opening eight inches square just back of each machine permits peels and cores to drop directly upon the belt, while the waste from the trimmers' side of the table is easily swept into the openings as it accumulates.

The work table shown in the plans has ample space for seven machines and for fourteen trimmers. With power parers kept in a good state of repair, six experienced peelers should, in a nine-hour day, easily pare enough fruit to keep a ten-ton plant going. The number of trimmers needed will depend upon the mechanical perfection and state of repair of the parers and to an even greater degree upon the character of the fruit. When working with good C grade fruit, three experienced trimmers may easily keep the tables clear for two machines, while with small culls or fruit having decayed spots or much codling moth injury, two trimmers to each parer may be necessary to properly trim the fruit. In any case, economy at the trimming table means fruit of poor quality which will find a market at less than prevailing prices for "prime" fruit.

The conveyor from the work table delivers the fruit to the bleacher, which is suspended from the joists, 6½ feet from the

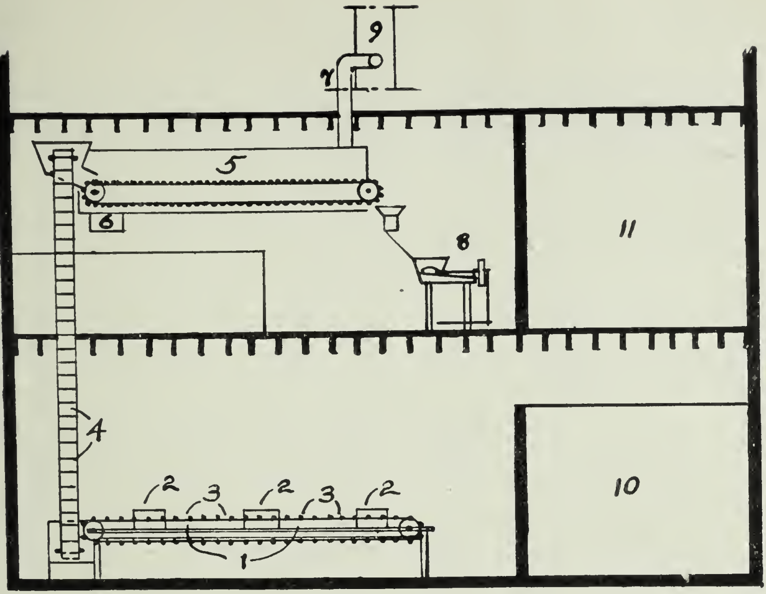


Fig. X. Sectional view of plant showing arrangement of conveyors. 1, paring table. 2, position of paring machines. 3, endless belt conveyor for pared apples. 4, elevator from end of paring table to hopper of 5, bleacher. 6, sulphur chamber of bleacher. 7, pipe of bleacher, opening into 9, flue of furnace. 8, slicer. 10, storage bin. 11, kiln.

floor, out of the way of those working in the room. The bleacher delivers the apples into a bin placed at such a height above the floor that they may be brought to the slicer by gravity, or they may pass directly into the hopper of the slicer when it is in operation. From the slicer the fruit may be received in a barrel or large box standing on a truck and pushed into the kiln by hand, or it is quite possible to construct a simple system of belt conveyors which will receive the fruit at the slicer and convey it to a point inside the door of the kiln which is being filled.

In the plan here given, the conveyors from the work table deliver both apples and waste upstairs. In case peels and cores are to be discarded or used for stock feed without being pressed for vinegar, the plan can easily be modified by

extending the waste conveyor so that it delivers at any desired point outside the building.

Plants of Larger Capacity. Figures XI to XIII present plans drawn by Mr. B. C. Coons of the Coons-Mabbett Co., Rochester, New York, for a model eight-kiln plant having an approximate daily capacity of 20 tons of apples, or a total capacity of 1000 to 1200 tons for a season of 50 to 60 days. Only the exceptional individual or community will have need for a plant of such capacity, and the plans are purposely generalized in order that they may be easily modified to make them suit individual needs. It may be pointed out that the building is as compact as it is possible to make it, hence cost of construction will be minimum, and that labor-saving machinery driven by power replaces hand labor wherever possible. The eight kilns are so arranged that free movement of air into each of them from any point of the compass is possible, which is not the case when kilns are arranged side by side in a long row of six or eight. The explanations accompanying the drawings, with the detailed descriptions of equipment employed in smaller plants which precede, make detailed description unnecessary.

DRYING OTHER MATERIALS THAN APPLES ON THE KILN

Since the kiln is primarily designed for the drying of apples, the preceding description of methods of handling the fruit is written with reference to apples. But the kiln can also be successfully used for drying pears, peaches, apricots, cherries, berries, and a wide variety of vegetables.

As the general method of treatment of each of these materials is identical, no matter what type of drying plant is employed, the following statements may be taken as a general outline:

Berries. Loganberries, raspberries, or blackberries intended for drying should be picked when fully ripe, but before they have begun to soften, as soft berries will mat together badly in drying. As berries are not treated with sulphur prior to

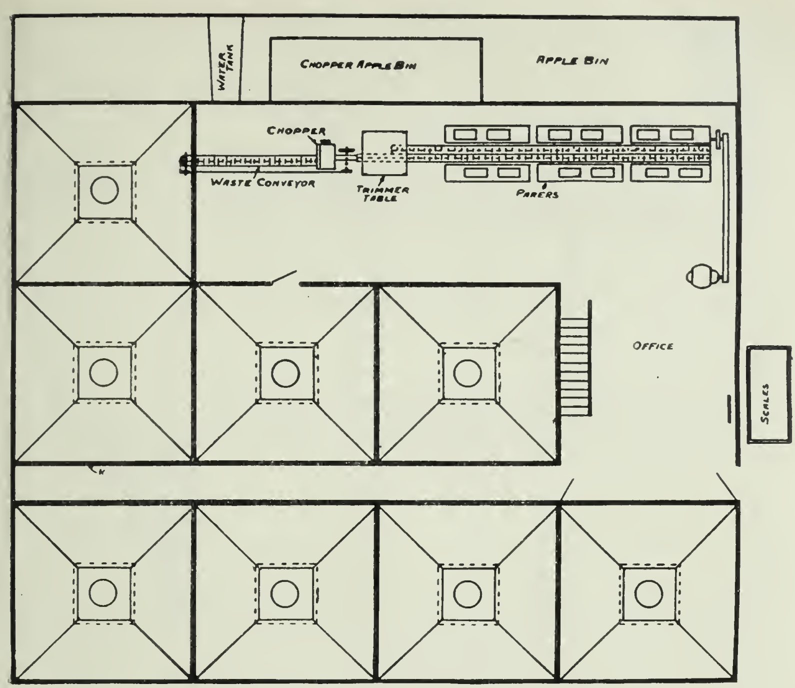
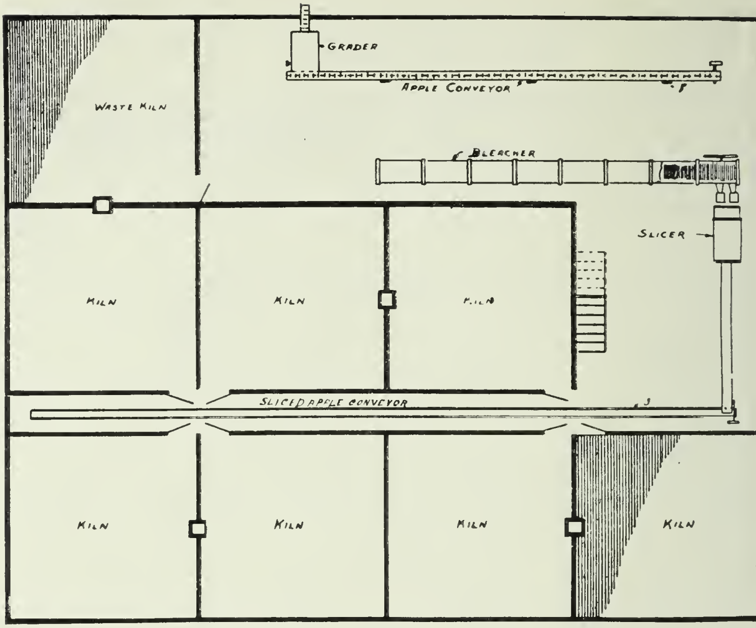


Fig. XI. First-floor plan, eight-kiln evaporator. Paring table arranged for double row of paring machines with trimmers at a separate table.

drying, they should be placed upon the kiln directly from the picker's vessels as rapidly as they are delivered at the plant, and should be spread in a uniform layer about two inches deep over the entire floor, avoiding unnecessary handling and making no attempt to remove leaves, stems, or other foreign matter, which are readily taken out by passing the dry berries through a fanning mill. The berries must be allowed to remain undisturbed for five to seven hours or until they have lost sufficient moisture to be stirred without crushing, when they are turned over by the careful use of a wooden shovel. As the drying proceeds they must be stirred from time to time in order to secure uniform drying. Berries are sufficiently dry when moisture can no longer be pressed out of them by crushing between the fingers and when they begin to rattle a



SECOND FLOOR PLAN

Fig. XII. Second-floor plan, eight-kiln evaporator. Grader has apple conveyor running longitudinally over paring table and opening at points marked F into hoppers which deliver apples by gravity to the paring table. Bleacher delivers apples to slicer, from which a conveyor carries them down the alley between kilns, delivering them at any desired point.

little when stirred with the shovel or rake. They should then be transferred, while still warm, to the curing room, where they are piled up, allowed to sweat, and stirred at intervals of a day or two, like apples.

Cherries. Cherries are rarely dried by artificial heat, but a very satisfactory product can be made by employing the methods used with berries. The fruit must be picked while still firm, picked over to remove stems, defective or burst fruits, spread to a depth of two inches on the kiln floor, which must be covered with burlap, and turned at intervals after they have become dry enough to be stirred without crushing.

Pears. Pears intended for drying should be picked when

"market ripe," before softening begins. They must be pared, cored, and cut into quarters by hand, as no machine which will do the work satisfactorily has yet been made. The equipment used for handling apples may be utilized in considerable part in work with pears, as the fruit may be delivered into the storage bin, carried through the washing tank to the conveyor, which delivers it in the storage bin on the second floor, from which it returns through the chutes to the paring table. The parers sit upon either side of the paring table, peel, quarter, and core the fruit with short-bladed knives, drop parings and refuse into the waste conveyor, and throw the clean quarters on the apple conveyor, which carries them to the bleacher, through which they pass to be received into boxes and taken to the kiln floor. They are spread in a layer four to six inches in depth; the subsequent treatment is identical with that for apples.

Apricots and Peaches. Apricots or free-stone peaches which are to be dried in halves without peeling are handled in the same way. The fruit is picked when well ripened, but not soft, and is washed and delivered to the paring tables as apples would be. The women at the paring tables reject over-ripe, soft fruits, cut each fruit cleanly in half by passing a knife completely around the fruit along the line of the suture, separate the halves by a gentle twisting motion, remove the stone with the point of the knife, and drop the fruit on the conveyor, which carries it through the bleacher. The spreading of the fruit upon the kiln floor is a task requiring considerable care. In any stone fruit, cut in half for drying, there will be oozing of juice from the pulp into the stone cavity at the outset of drying. Unless the pieces are placed with the stone cavity up, much of this juice, which is of course rich in sugar, will be lost, thus giving an inferior product low in weight and in nutritive value. Hence the fruit must be spread by hand, taking care to turn most of the pieces with the stone cavity uppermost, at least in the first one or two layers. The thickness of the layer of fruit on the floor should not be more than three inches, two inches would be better; the shorter time required for drying will compensate for the smaller

volume of fruit handled at one charge. The fruit must not be stirred until the drying has proceeded so far that the juice has dried to a waxy consistency, when it may be examined and any portions which are drying too slowly, turned over. When almost dry the fruit may be shovelled over as apples are, but stirring in the earlier hours must be avoided.

When peaches are to be peeled and sliced, hand parers may be installed on the paring tables and the fruit placed in the conveyor as it is pared, carried through the bleachers and delivered into boxes. A temporary work table is placed upstairs for the slicers, who take the fruit as it comes from the bleacher, slice it, and place it in boxes for transfer to the kiln. This is the most efficient and economical method, as it is impossible to properly bleach the fruit after it has been sliced. On the kilns, peeled and sliced peaches are treated precisely as apples except that the fruit should not be spread quite so deeply, a four-inch layer giving best results.

Prunes. It is practically impossible to dry plums or prunes satisfactorily or economically upon a kiln drier. They must be dried upon trays in order to obtain good results, hence a tunnel or Carson-Snyder drier should be built wherever prunes normally make up a considerable part of the material to be dried. The special methods of treatment necessary in preparing prunes for drying are discussed in detail in the section on the drying of fruits in tray driers, page 79.

THE PREPARATION OF VEGETABLES FOR DRYING

The preparatory treatment of any vegetable will be as here outlined, whether it is to be dried upon a kiln or upon some type of drier employing trays.

Root Vegetables. In handling root vegetables, as potatoes, sweet potatoes, carrots, parsnips, turnips, and beets, a considerable part of the equipment used in handling apples can be employed. From the storage bin the roots are delivered into the washing tank, carried to the second floor storage bin by conveyors, and supplied to the work table by the gravity chutes as apples would be. The parers sit at either side of the

table, and use short-bladed knives to pare the roots, cutting out all decayed and discolored portions and placing the peeled roots on the apple conveyor, which delivers them into the bleacher. Bleaching is as necessary with potatoes, carrots, turnips, or parsnips as with apples or apricots and for the same reason, namely, that rapid oxidations and consequent discoloration of the product rapidly occur unless thorough bleaching follows promptly after paring.

From the bleacher the material may be delivered into boxes or directly into the hopper of a root chopper. Several cheap, durable machines, both for hand or power operation, are on the market, and are used both for slicing roots and for cutting up small unpared apples—"chops"—for vinegar and jelly making. From the chopper the sliced roots are transferred to the kiln, spread uniformly to a depth of six inches, and handled like apples.

Onions are prepared for drying by cutting through the base deeply enough to free the outer colored scales, removing these with the tops, and slicing the bulb, either by hand or in a root chopper, into slices one-fourth or three-sixteenths of an inch in thickness. Since the slices readily separate in handling and do not pack closely together while drying, they may be spread upon the kiln floor to a depth of seven to eight inches.

Tomatoes may be prepared for drying by subjecting them to live steam for five minutes, stripping off the outer skin, and trimming the stem ends with a knife, or they may be pared with the knife just deeply enough to remove the outer skin. In either case the fruit must not be cut open, and best results will be obtained in drying by spreading them in a single, closely-placed layer upon the floor.

Cabbages are freed from the loose outer leaves and the central stalk, and the heads are then cut into slices about one-quarter inch thick by parallel cuts, after which the slices are cut across several times. The writer has seen very effective cabbage slicers which consisted of six to ten parallel blades about one-fourth inch apart, fastened into a metal frame to which a handle is attached. Two or three strokes with this im-

plement cut the largest cabbage into slices which are then subdivided by a cross cut. Cabbage, in common with green beans, green peas, and corn, must be steamed for a short time before drying begins. If the plant contains a boiler it will be easy to arrange to pass a jet of steam into a tight vessel in which the crates or boxes of material can be placed for steaming. If the plant has no boiler, any large vessel with a light lid which can be heated over a stove may be made to serve as a steam-chest, by fitting it with a false bottom to hold crates above the water level. Set the boxes of sliced cabbage or prepared beans or peas into this vessel for from five to seven minutes, then spread them upon the drying floor.

Green Peas or Green Beans are picked just before the shells begin to become tough, washed, the strings are removed and the longer pods broken as would be done for cooking. They are dropped into crates or baskets as they are prepared and the vessels are placed in the steam box for from six to eight minutes. Either peas or beans may be spread to a depth of four to six inches on the kiln.

Green Corn should be gathered after the ears have become well filled but before the kernels have begun to harden, husked, freed of silks as completely as possible, and steamed for about five minutes. The grains are then sliced from the cob by deep cuts which remove all but the extreme tip of the grain. The kiln floor must be covered with burlap, and the layer of corn can not be made more than 2½ to 3 inches in depth.

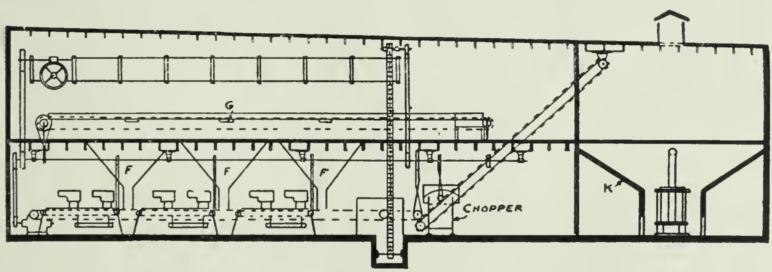
Pumpkin is cut into slices about 1½ to 2 inches wide, peeled and freed from seeds, and the strips cut across into blocks one to two inches long. These are spread to a depth of three inches on the kiln.

HEATING APPARATUS

Each kiln of the plant must have its own heating unit. A kiln floor not larger than 20x20 feet in size can be very satisfactorily heated by means of a large hop stove. A very satisfactory stove of this type, made by two or three Northwestern manufacturers, has a firebox 54 inches long, 18 inches

wide, and 24 inches high, with a door 15x18 inches, thus permitting the use of four-foot cordwood. Such a stove should weigh not less than 600 to 650 pounds, in order that it may stand up under the continuous firing necessary. Where hard coal is available at prices under $9.00 per ton, it may be used instead of wood, and the large cast-iron evaporator furnaces weighing 1500 to 2000 pounds each, universally used in Eastern evaporators, will then be the most satisfactory heating device. Soft coal can not be used in any type of furnace, since the pipes promptly become clogged, while the opening of the door in firing permits the escape of clouds of soot, which settles upon the fruit and completely ruins it in so far as appearance and possibility of marketing it are concerned. Since the prices of hard coal entirely prohibit its use in the Northwest, wood is the only fuel which can be successfully and economically used in heating kilns.

Another very satisfactory source of heat is a well built stone or brick furnace, properly lined with the best quality of fire brick. Such a furnace should be at least four feet wide and deep enough to take wood in eight-foot lengths of any size that one man can readily handle. If the walls are properly laid with a good quality of mortar, such a furnace is practically everlasting except that the fire brick lining will need repairs and partial replacement every second season, while the first sections of pipe will scarcely stand more than one year's use.



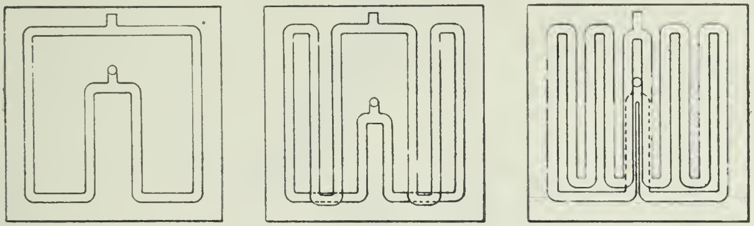
SIDE ELEVATION

Fig. XIII. Sectional side elevation, eight-kiln evaporator. K, kiln with jacket-and-hopper construction. Paring table has endless belt conveyor to trimming table, from which the elevator delivers to bleacher. Endless belt from grader delivers apples to hoppers F over paring tables through openings marked G.

The piping of the furnace is extremely important, since the operator must depend upon th earrangement of his pipes both for utilization of the heat produced and for its uniform distribution to the drying floor. Several systems of piping are in use, each with a number of strong advocates, but all are alike in that they use in an 18x18 or 20x20 foot kiln, 175 to 250 feet of 8 or 10 inch pipe, disposed in a series of loops or coils beneath the kiln floor. The description which follows, if studied in connection with the diagrammatic sketches (Fig. XIV, A, B, C) will make the method of arrangement clear. The "single pipe system," in which the piping makes one circuit about the room, is used where the location of the building or the construction of the flues makes it impossible to secure an ample draft. The "double pipe system," in which the pipe, after being carried around the walls, is brought back across the floor before it passes into the flue, is used in kilns of large size or wherever ample draft can be secured. The double pipe system is preferable, since more of the heat is utilized and its better distribution to the floors results in more uniform drying than can be secured by the single system.

No matter what system of piping may be adopted, connection with the furnace collar is made by means of a section of special double thickness Russia iron pipe, 10 inches in diameter. This is fitted with a T joint, the whole standing erect and rising to about 4½ feet below the kiln floor. To the T elbows are fitted, and two parallel lines of pipe 10 inches in diameter are led from these across the room to a point directly opposite the chimney and about 22 inches from the wall. These pipes are given such an inclination as will bring them at this point to within 3½ feet of the kiln floor; a nearer approach would be dangerous because of the high temperature of the pipes. At this point elbows are fitted on and the two pipes are carried in opposite directions around the walls of the room to the flue. In case the "single pipe system" is used, these lines may be given sufficient upward inclination to bring them to within 24 to 30 inches of the floor at the flue, where the two pipes are united by means of a T joint fitted with dampers, which enters the

flue (Fig. XIV A). If the double pipe system is to be used, the rise given the pipe to this point must be more gradual, and the two lines, instead of being united, are carried back and forth across the room in one of the methods indicated in the diagrams (Fig. XIV B, C) with such upward inclina-



A B C

Fig. XIV. Systems of piping which increase efficiency of furnace. A, single pipe system, used in small kilns or when jacket-and-hopper construction is employed. B, double-pipe system, employed in large kilns or tunnels. C, a still more efficient double-pipe system.

tion as will bring them to the flue not less than 20 to 24 inches from the kiln floor. In the double pipe system, 10-inch or 9-inch pipe is generally used for the first circuit of the walls, while 8-inch pipe may be used for the remainder of the system. Wires or light chains are used to suspend the pipe from the joists of the kiln floor.

In order to prevent overheating of the area immediately above the furnace, a deflector is employed. This may be simply a sheet of iron having the same dimensions as the furnace and spiked to the lower edge of the joists. A better plan is to cut and fold the edges of the sheet so as to give it the form of a low, flat inverted hopper, and to suspend it by means of chains so that it may be raised or lowered with changes in the temperature at which the kiln is being operated.

The efficiency of the furnace may be very considerably increased and the expense of piping materially reduced by the adoption of the "jacket-and-hopper" plan of construction in the furnace rooms. In this plan of construction the furnace is enclosed, at a distance of 12 or 18 inches from its walls, by a wall of stone, brick, or concrete which rises to a

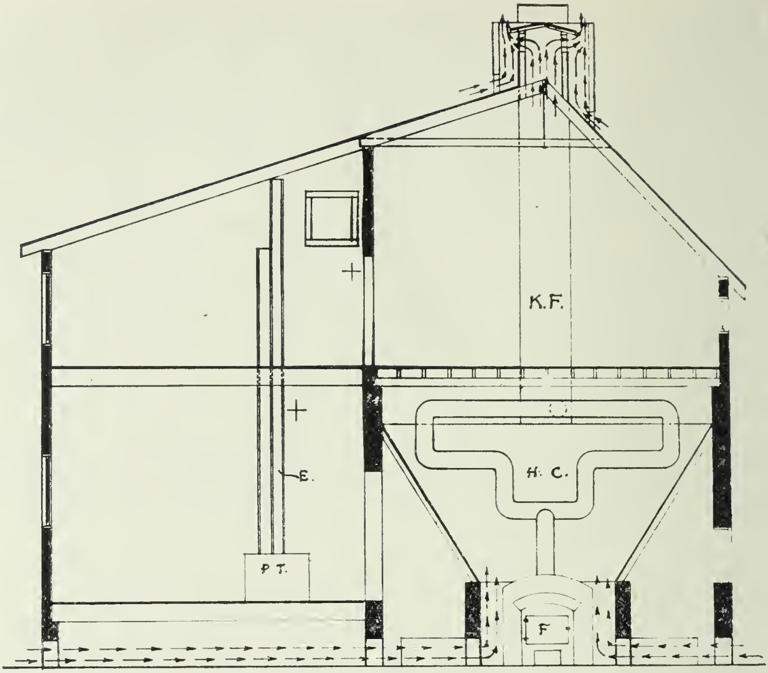


Fig. XV. Sectional end view of building, showing jacket-and-hopper construction. F, furnace, enclosed by jacketing wall upon which base of hopper rests. H.C., coils of piping. K.F., kiln flue. Paring table and elevators for apples and waste, position of bleacher, and location of shafting are also indicated, as is the construction of the ventilator.

height of about six feet, thus forming a rectangular box inside which the furnace stands. Each wall of this structure has at its middle an opening 3 feet in length by 18 inches in height, placed 6 inches above the floor level, with a larger opening closed by a sheet-iron door through which the furnace tender enters at the front of the furnace. Upon the "jacket" thus formed, the "hopper" is built by constructing a frame of 2x4 scantling extending from the top of the jacket wall outward and upward to the wall of the room just below the kiln floor. Upon the frame thus made, perforated metal lath is nailed and the "hopper" is completed by covering the lath with a 3/8 or 1/2 inch layer of cement. The furnace thus

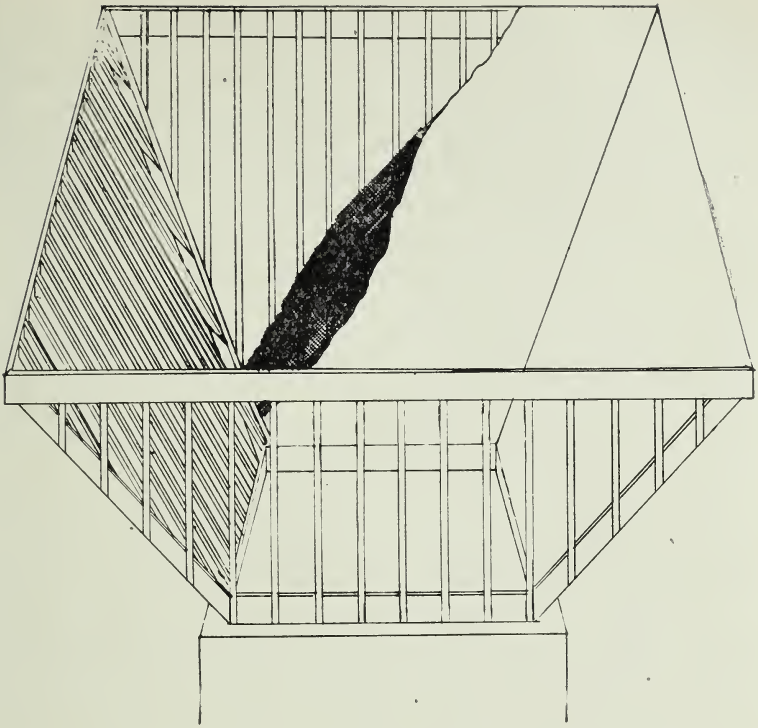


Fig. XVI. Detail of jacket-and-hopper construction. Detail of framing of hopper shown on left-hand side and front, framing covered by metal lath with cement partially in place at back.

stands at the bottom of a shallow, flaring hopper which is roofed by the kiln floor, with a current of air entering through the ventilators of the jacket, becoming warmed as it passes over the furnace and rising through the floor above. See diagram, Fig. XVI. This arrangement reduces loss of heat by lateral radiation to a minimum, gives more uniform distribution of the heat to all parts of the kiln floor, and permits the use of the single pipe system with satisfactory results. Some operators claim that the efficiency of their plants is increased 25 per cent by the adoption of this arrangement, since the time required for drying is materially shortened even when the floors are more heavily loaded with fruit.

The chimney should be built in the common wall between two kilns. It should rest upon a solid stone or concrete column extending up to within 18 inches of the point of entrance of the flues. There should be no air openings into the chimney below the flues, as they will increase the consumption of fuel and cause trouble in other ways. The chimney should be 16 inches square if two flues open into it. Many operators insist that better results are obtained if the chimney is made double all the way up, each opening being 10x12 or 12x12 inches, but the writer has seen so many plants with two kilns piped into a single 16x16 flue that he thinks a separate flue for each pipe entirely unnecessary. The chimney should extend far enough above the roof to insure good draft and to prevent damage to fruit by the blowing of smoke and soot down the ventilators on windy days.

The Kiln Floor. The kiln floor is constructed of wooden strips, or slats, usually ⅞ or 1 inch square, but beveled on two sides so that one face is ½ inch wide. These are nailed to the joists, narrow face down, and are spaced ¼ or ⅜ inch apart. There are thus left narrow openings through which the warm air rises, and as the beveling of the slats makes these openings wider below than above, they can not become clogged by particles falling through. In the Eastern evaporators, kiln slats are made of basswood, maple, beech, or poplar, and many makers and dealers in evaporating machinery carry such slats in stock. Hop kiln slats are usually 1½x1 inches thick and have one of the 1-inch faces rounded. They are placed 1½ inches apart with the rounded face uppermost. A floor so made can be used for drying fruit if covered with burlap; the use of the narrower slats placed nearer together makes burlap unnecessary except when drying berries.

Any hard wood which does not impart flavor to the fruit or warp badly can be used, but fir or other coniferous wood is worse than useless, as the constant high temperature will bring out the resin and give the fruit a persistent odor and flavor which ruins it.

After the kiln floor is in place, it is oiled a few times at intervals of two or three days with lard oil, paraffin oil, or a

mixture of boiled linseed oil and tallow, applied very hot, in order to thoroughly saturate the slats. This prevents sticking of the fruit. After the kiln is in use, one or two oilings each season will keep the floor in good condition, but it should be thoroughly scrubbed with strong, hot soapsuds at least once, preferably twice, each week during the season.

EVAPORATORS EMPLOYING TRAYS

Wherever prunes, berries, peaches, and apricots, or any one of these, contributes largely to the total volume of fruit to be dried, some type of drier in which the material is spread upon trays for drying should be built. The first cost of construction of such a drier, plus the cost of making and repairing or renewing trays, is greater than that of a kiln of equal capacity, and the operating costs are also somewhat greater, since more hand labor is required in spreading trays and caring for the drying fruit. The great advantages of such evaporators are that the material to be dried is spread in a thin layer upon the trays and need not be stirred until almost dry, hence it is possible to dry the more delicate berries without the crushing and loss of juice which is almost inevitable upon the kiln, while such slow drying fruits as prunes can be satisfactorily handled only upon trays. Since any properly constructed tray evaporator will successfully dry any fruit or vegetable capable of being dried at all, the district devoted to general fruit and vegetable growing, or that having a considerable acreage of prunes, should build one of the two types of evaporators—the tunnel or the Carson-Snyder—described in the following pages.

THE TUNNEL EVAPORATOR

The need of the prune growing districts of the Northwest for an efficient and economical method of drying prunes led to the development in the early nineties of a great variety of evaporating machines. In a publication entitled "Prunes in Oregon," issued as Bulletin 45 of the Oregon Agricultural Experiment Station in June, 1897, Professor U. P. Hedrick,

at that time horticulturist of the Oregon Station, described seven types of prune evaporators, each known by the name of its manufacturer or patentee, then in use. Two years later J. A. Balmer, horticulturist of the Washington Agricultural Experiment Station (Prunes, Bulletin 38, Washington Agricultural Experiment Station, May, 1899), described four of these evaporators with at least two others, as being at that time rather generally used in Washington. Of all these types of evaporators, only two have stood the test of years of practical use, and it would probably be impossible to find one of the others in operation at the present time.

The prune tunnel or tunnel evaporator as used today in the Northwest has been gradually perfected by modification of the ''Allen Evaporator,'' manufactured and patented by W. K. Allen, of Newberg, Oregon, and described by both Hedrick and Balmer in the publications just cited as being in rather general use at that time in Washington and Oregon. In so far as one can judge from the rather unsatisfactory drawings and descriptions given by these authors, the original Allen evaporator had most of the essential desirable features of the modern tunnel, with the very great disadvantage that the fruit, once placed in the tunnel, was out of sight or control of the operator until drying had been completed.

In its essential features the tunnel evaporator consists of a long, narrow room, with the floor and ceiling inclined uniformly from end to end, and with a furnace below the floor at the lower end. The room is cut into a series of narrow chambers, the ''tunnels,'' by parallel partitions, which may be solid or merely an open framework of slats. In the original Allen evaporator the trays upon which the fruit was spread were loaded upon trucks fitted with an open framework to support and separate them, and these trucks were rolled in one behind another at the upper end of the tunnel until it was filled. The dry fruit was removed at the lower end of the tunnel by withdrawing the truck carrying it, when the others moved down by force of gravity, permitting a new truck to be rolled in at the upper end. This arrangement was objectionable in that the upper and lower

trays of any given truck did not dry at equal rates, necessitating overdrying of the lower trays or transfer of the upper ones to another truck, and even more objectionable in that the operator could not learn how the fruit toward the middle of the tunnel was drying except by rolling out all the trucks until that which he desired to inspect was reached. Consequently, trucks are no longer generally employed in tunnel evaporators, and have been replaced by an arrangement which permits individual trays to be moved with little difficulty. To build this, the indivdual tunnels of a group or series are separated one from the other by partitions or at least by a framing of 2x4 studs. To these partitions or to the studs are nailed a series of cleats, usually made of ⅞ or 1 inch strips, 2 inches wide, nailed flat, extending from end to end of the tunnel parallel with the inclined floor, and placed at equal distances, preferably four inches from center to center, apart. These cleats form a series of tracks, one above the other, which support the trays upon which the fruit is spread, and the tunnel is filled by pushing the trays in one after another at the upper end of the tunnel, and moving them along the tracks until all are loaded. The heated air is admitted at the lower end of the tunnel, from a furnace placed in the room beneath, rises through the successive series of trays, and passes off, loaded with moisture, through a ventilator shaft at the opposite higher end. Steady air movement is secured by an arrangement of air intakes in the furnace room, essentially identical with that already described for the kiln evaporator.

All that has been said in the preceding pages as to the relative merits of various building materials for constructing kiln evaporators applies equally well when the plant is to be of the tunnel type. The advantages and economy of permanent fire-proof construction are the same, as is the necessity for having the portion of the building in which the actual drying goes on as nearly air-tight as possible and with the loss of heat by radiation reduced to the lowest possible minimum.

The plans presented in Figures XVII to XXI are those of a drier having nine tunnels, each 20 feet in length and three

feet in width, with a total capacity of ten tons of prunes or apples at one loading. The space devoted to the storage of trays not in use, dried fruit, and fruit awaiting preparation for drying will ordinarily be ample for a plant of this capacity. There are two workrooms; that on the first floor is used for the preparation of apples, pears, and such other fruits or vegetables as require paring and trimming. Washing tank, grader, power conveyor to storage bin and grivity chutes from this bin to the paring table, with conveyor for carrying the pared and trimmed fruit to the bleacher on the second floor, are identical with those employed in kiln evaporators and are used in the same way. The workroom on the second floor has in it the bleacher, the apple slicer, the dipping tank for prunes, and the spreading tables, and its floor is level with the floor of the higher end of the tunnels. Pared apples or roots pass through the bleacher and slicer and are then conveyed to the spreading tables, while peaches, pears, or apricots go from the bleacher to the spreading tables. On the outside of the building an inclined platform leading to the door of the second floor workroom makes it possible to deliver berries or prunes directly to this room from the wagons, so that berries are taken to the spreading tables, or prunes to the dipping tank as rapidly as they are received. Trays are stored here, since all fruit is placed on trays and put into the tunnels in the second floor workroom, while storage for dried fruit is provided on the lower floor, to which it is delivered through chutes as it is taken from the drier. This arrangement avoids the inconvenience and congestion which necessarily occurs when the equipment for handling all fruits is placed in one room, and also dispenses with the necessity for an elevator or other means for lifting the spread trays from the ground floor workroom to the level of the upper end of the tunnels.

The plans here given can easily be adapted by the individual builder to his particular needs. If larger capacity is desired, the general plan of the building remains unchanged, but it is enlarged sufficiently to acommodate the additional tunnels desired and to give space in the workrooms for the longer

paring and spreading tables needed by the increased working force.

The Tunnels. The number of tunnels to be constructed must be determined in every case by the volume of fruit to be handled. It needs to be emphasized, however, that the length and size of the individual tunnel is not to be modified at the pleasure of the builder. It is usually difficult or impossible to secure satisfactory and economical results with tunnels more than 20 feet in length, since further increase in length retards air movement and therefore slows down the

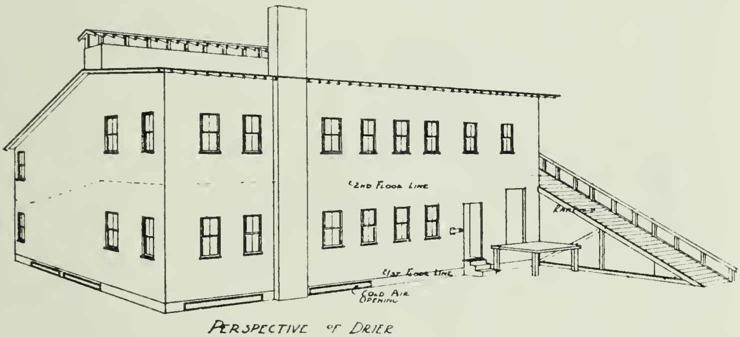


Fig. XVII. Front elevation of ten-ton prune-tunnel drier, showing ramp for delivery fruit from wagons to second-floor work-room.

drying. A tunnel higher than six feet or carrying more than 16 or 18 tiers of trays will dry very slowly on the upper trays, while the work of removing or inserting trays at the top will be inconvenient and fatiguing. For the sake of convenience in handling, three feet in width and four feet in length should be the limit in size of the trays. Consequently, tunnels 20x6x3 feet are as large as can be efficiently operated, and attempts to increase any of the dimensions are likely to result in constant trouble and lowered efficiency. A tunnel of the dimensions just indicated will carry 18 tiers of five 3x4 trays, or 90 trays, each having a drying surface of 12 square feet. Each tray when spread to a depth of 1½ inches with apples will hold about 25 pounds of fresh fruit, giving a total capacity of 2250 pounds, a quantity which

would be yielded by from 65 to 70 bushels of apples. Such trays will carry 25 to 30 pounds of prunes or 16 to 20 pounds of raspberries or loganberries. The time required for drying will depend to such a degree upon the circulation of air through the tunnels that any statements must be taken as only indicative of what may be expected; apples will require 10 to 16 hours, berries 12 to 17, and prunes 28 to 40 hours at the temperatures recommended in a later paragraph.

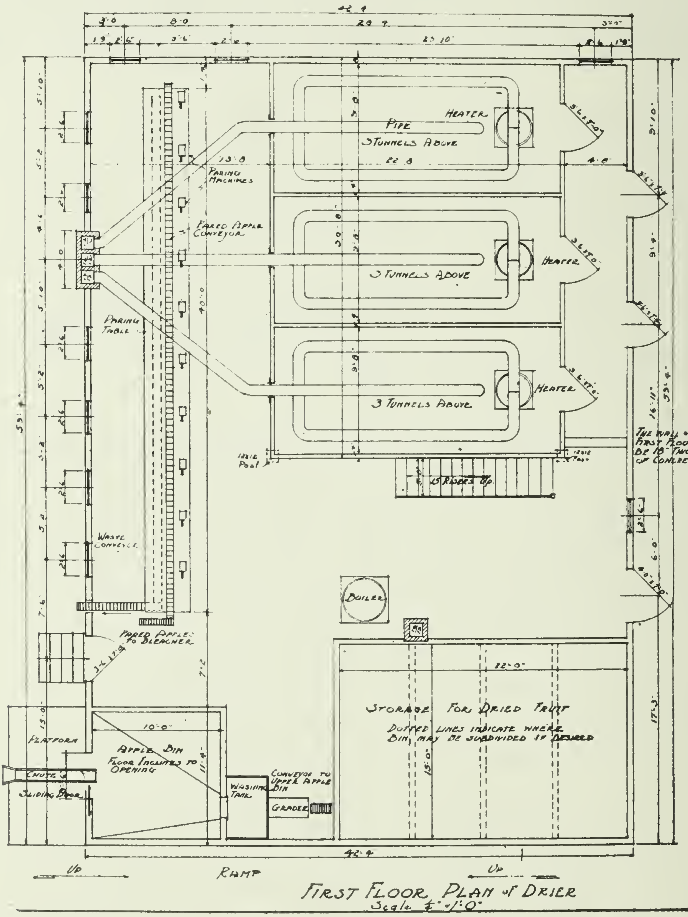


Fig. XVIII. First floor plan of ten-ton prune drier, showing furnace rooms, bins for receiving apples and storing dried fruit, and paring table with conveyors for handling apples.

The floor of the tunnel slopes uniformly from end to end, the inclination most generally employed being $1\frac{1}{2}$ or 2 inches per foot of length. Two differing types of construction are employed; in one the tunnel is tightly floored with sheet

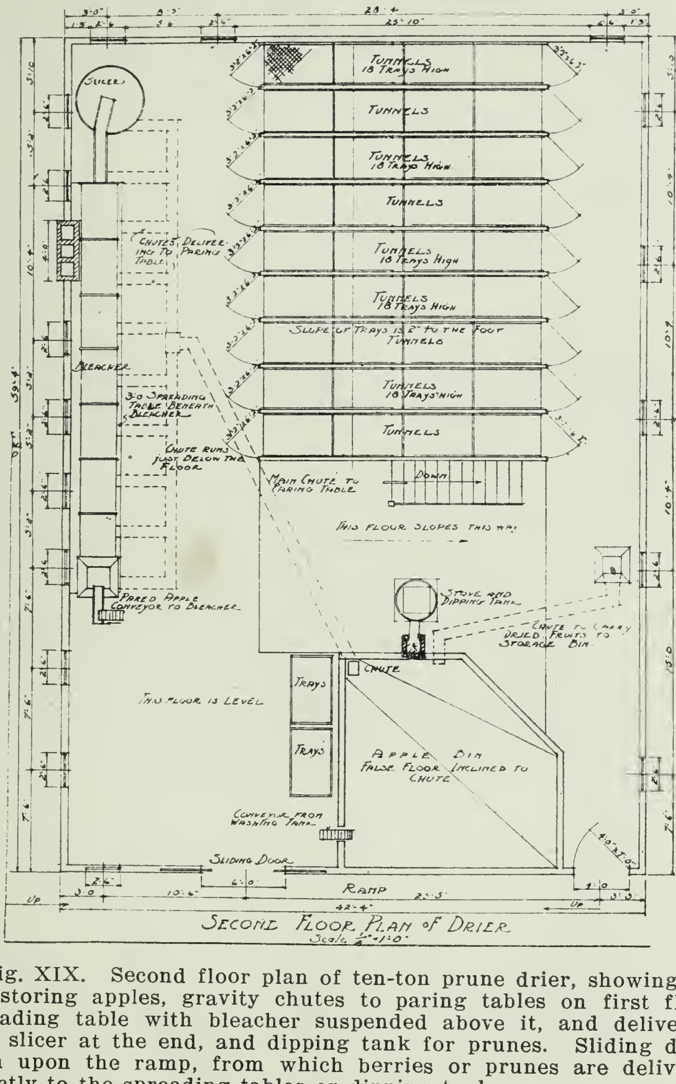


Fig. XIX. Second floor plan of ten-ton prune drier, showing bin for storing apples, gravity chutes to paring tables on first floor, spreading table with bleacher suspended above it, and delivering into slicer at the end, and dipping tank for prunes. Sliding doors open upon the ramp, from which berries or prunes are delivered directly to the spreading tables or dipping tank.

iron throughout its length except for a distance of two to four feet at its lower end, which is directly over the furnace. In the second type the tunnel has no floor, but is continuous with the furnace room. In either case the furnace stands beneath the lower end and an arrangement of piping similar to that described as being used in kiln evaporators distributes the heat throughout the length of the tunnel. Each of these arrangements has its strong advocates; that last described obviously makes somewhat better use of the heat produced by the fuel.

If a number of tunnels are to be constructed it is advisable to build them in sets of three arranged side by side and heated by the same furnace. In case the tunnels are to be constructed in blocks of three, the furnace room should be made of the same size as the block of three tunnels, except that it is two feet longer, or 22x10 feet inside the walls. This added two feet gives space for the furnace, which is to be set at the lower end of the tunnels (see diagram Fig. XXI). The walls of the furnace room may be built of stone, concrete, concrete blocks, or metal lath and plaster. The outer walls of the group of tunnels are merely upward continuations of the walls of the furnace room and may be built of matched lumber nailed to 2x4 framing, or better, of non-inflammable material, as sheet iron or metal lath and plaster.

The two ends of each tunnel are formed by the doors, which must be close fitting, of a height and width equal to the inside dimensions of the tunnel, and must swing back far enough to permit ready insertion or withdrawal of trays. The roof of the tunnels should be of matched lumber. The ventilating shaft, for three tunnels each 20x3 feet, should be not less than 5x2 feet in cross section, should have a damper at its base, and should extend well above the peak of the roof of the building. (See diagram IV).

The partitions separating the individual tunnels are built of matched lumber and are carried up to within 6 to 12 inches of the roof of the tunnel. Some operators omit these partitions entirely, merely making a framework of 2x4s to which the cleats which support the trays are nailed, so that the

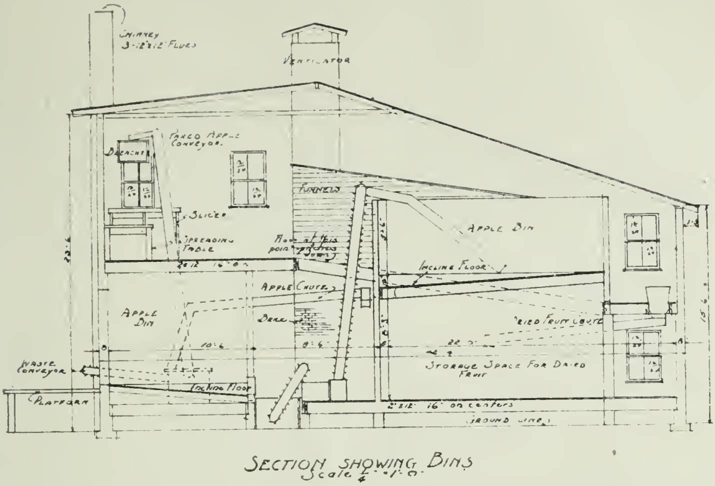


Fig. XX. Section through prune drier, showing bin for apples with conveyor from grader and gravity chute to paring table, conveyors from paring table to bleacher, spreading table, and chute and storing room.

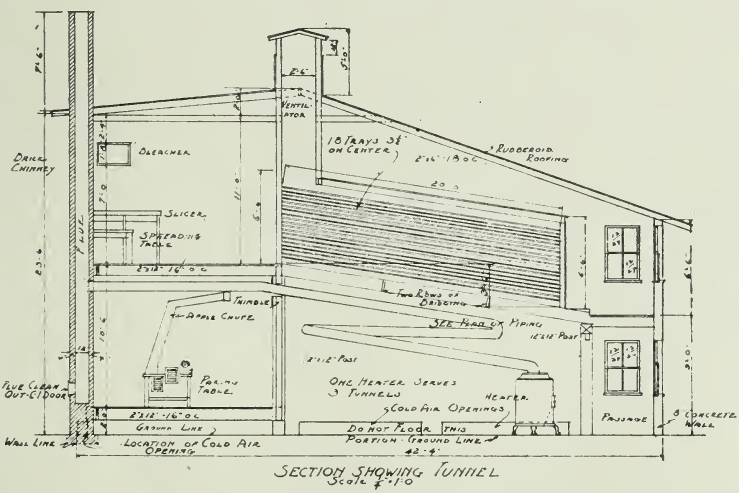


Fig. XXI. Section through prune drier, showing tunnel and ventilating shaft in section, arrangement of furnace and piping, and cold air inlets in the walls of furnace room.

whole interior of the three tunnels is one continuous chamber. If the tunnels are walled up, the opening of one of the doors to insert or withdraw trays interferes with the drying in that tunnel only, whereas in the absence of such walls, the opening of any door results in the cooling down of the entire system. Even were this not the case, the more uniform and rapid movement of air through the tunnels and the comparative freedom from dead air pockets secured by the separating walls well repays the expense of their construction.

The Furnace Room. If built in accordance with the suggestions made above, the furnace room will be 22x10 feet in size. The height to the floor at the lower end of the tunnel should be 7 feet; a rise of 1½ inches per foot in the floor would give a height of 9½ feet at the opposite end, while a 2-inch rise would give a height of 10 feet 4 inches. The walls may be of stone, brick, concrete, sheet iron or metal lath and plaster; if built of wood they must be lined with asbestos sheeting to reduce the danger of fire. Since the cost of such a lining will bring the expense of construction very nearly up to that of a concrete wall, it is the part of wisdom to cut the fire risk to a minimum by avoiding wood altogether.

Adequate provision for an abundant supply of air is absolutely necessary. For three tunnels of the size here suggested, the furnace room should have four air inlets, one in the center of each of the walls, each 3x1½ feet in size and placed about six inches above the ground. These will give a total air inflow of 2592 square inches. It will rarely be necessary to open all of the inlets to their full capacity, and sliding doors should be provided in order that any of the inlets may be partially or wholly closed at will, but there will be an occasional still, humid day when the entire capacity of the air intakes will be needed.

If the furnace room occupies only part of the lower floor of a larger building, provision must be made for free access of air to the intakes on the enclosed sides. This may best be secured by excavating the furnace room to a depth of 12 to 18 inches, elevating the floor of the remainder of the building,

and providing numerous ventilating openings in the foundation walls through which air may move freely beneath the floors to the furnace room inlets, as indicated in plans, Figs. XVII, XXI.

The Furnace. The statements made in the section devoted to heating apparatus for kilns hold true here. The most economical and durable heating equipment is a well built brick or stone furnace lined with fire-brick, of sufficient height and depth to take ordinary cordwood without preliminary splitting or cutting to shorter lengths. The heavier top stoves, weighing 600 to 800 pounds, and long enough to take cordwood, are also very satisfactory.

If the tunnels are floored except for a distance of three to four feet at the lower end, the furnace should stand immediately below this opening in order that the heated air may pass directly upward into the lower end of the tunnels. The fact that the furnace room is two feet longer than the tunnels permits the furnace to stand in this position. The chimney should be placed at one side of the building, the pipe rising from the furnace should be fitted with a T joint, and the two lines of pipe carried around the walls of the room before they are connected with the flue, as described in the section on piping of kiln furnaces, page 50. If the floors are of sheet iron, the pipe may be brought up to within 24-30 inches of the floor and kept at that distance in its passage around the room; if the tunnels have board floors or no floors at all, it must be kept about a foot lower to prevent overheating. The "single pipe" system of piping will give sufficient radiating surface and the distance of the pipes from the side walls should not be less than 24 inches. The pipe should be of the quality recommended for use with kiln furnaces and should be 9 inches in diameter. The chimney should be at least 12x12 inches inside, if only one furnace is piped into it, 12x18 if two are connected with it. It should be solid up to within 18 inches of the entrance of the pipes and should extend 4 or 5 feet above the tops of the ventilators. As free access to both ends of the tunnel is necessary, the chimney should stand at the side of the building, with the pipe passing beneath the floor to reach it, as shown in Fig. XVIII.

The Construction of Trays. Trays are best made from $\frac{7}{8}$x1½-inch slats. Cut two pieces 3 feet and two pieces 4 feet long, nail these together to form a rectangular frame, 4x3 feet and 1½ inches deep. Cut a piece of wire netting 1 inch larger each way than the frame, turn the edges back to give a firmer hold for nailing, and nail the netting to the frame. Now cut a second set of slats, and nail these to the bottom of the tray, taking care that the wire is not allowed to project. Lastly, nail a wooden strip across the middle to prevent warping of the frame. This gives a reversible tray which has no projecting wires to tear clothing and hands or catch in the tunnels. The bottom cannot become loose from the frame, and can be kept from sagging by using the tray either side up.

Trays should be made of the best grade of galvanized wire screen obtainable, with meshes 1-4 to 1-5 inch square. An inferior, poorly galvanized wire will be attacked by the acid juices of the fruit with discoloration and injury to the product. The German government has long made strenuous objection to the use by her people of apples dried on wire trays, on the ground that such fruit may absorb sufficient quantities of zinc to be injurious to consumers. While this claim is not borne out by the results of chemical analysis, it has resulted in laws prohibiting the sale in Germany of apples containing more than a specified amount of zinc. While this amount is much less than is found in fruits dried on well-galvanized trays, it may be reached or exceeded when an inferior wire is used in making trays or when trays become rusty from long continued use. The employment of wooden trays offers a theoretical solution of the difficulty, but unfortunately there are practical difficulties which prevent their use; such trays are expensive to make and heavy to handle, the strips making up the bottom must be so narrow, in order not to impede the circulation of air, that they are very fragile unless made of some hard, tough wood as hickory or rattan, and the fruit sticks rather badly unless the trays are oiled. For all these reasons, the use of metal trays seems practically unavoidable, but the operator should promptly discard those in which the destruction of the zinc coating has occurred. To

paint such trays with white lead, as some operators do, is simply to add the more poisonous metal lead to the fruit, and such treatment of trays is fraught with danger of serious consequences to the consumer of the product.

The Operation of the Tunnel Evaporator. The method of operation of the tunnel evaporator differs from that of other driers in two respects; first, the fruit is subjected at the beginning of the process to a very moderate temperature which is steadily increased as the drying proceeds; second, the warm air at its first entrance to the tunnel comes into contact with the dryest fruit, then with that containing more and more water, until it reaches fresh fruit and becomes saturated with moisture immediately before finally passing out of the tunnel. It is generally claimed that such fruits as apples and berries retain more of their natural flavor when subjected to a temperature not higher than 120-135 degrees Fahrenheit in the first hours of drying, but that the temperature may advantageously be gradually raised to 150-165 degrees after the fruit has given up a portion of its water content. There is the additional advantage that berries kept at 120-135 degrees until drying is well begun do not have their cellular structure broken down, hence do not run together into compact masses, while neither berries, prunes, nor apples lose a portion of their sugar by "bleeding" or dripping, as is the case when materially higher temperatures are used at the outset. Consequently a heavier product with a larger sugar content is obtained by maintaining a moderate temperature at the outset, facilitating the drying by increasing the heat only after the fruit has lost so much water that dripping no longer occurs. The tunnel evaporator provides at one time the various temperatures needed, since it is hottest at the lower end, directly over the furnace, and the temperature steadily decreases toward the upper end; also the temperature at any point near the top of the tunnel is considerably below that at a corresponding point near the bottom. Consequently fresh fruit introduced at the upper end of the tunnel, near the top, and pushed along the tracks until it is finally removed

dry at the lower end, is subjected to a steadily increasing temperature throughout its stay in the tunnel.

The second distinctive feature of the tunnel evaporator has an obvious advantage. The heated air upon entering the tunnel passes over fruit which is almost dry and which consequently gives up only a small fraction of the amount of moisture which the air is capable of carrying. Thence the air rises through successive layers of fruit, each containing more moisture than its predecessor, until finally, just before entering the ventilator shaft, it passes over trays which have just been inserted. The tunnel thus exactly reverses the method of the old tower evaporator, in which fresh fruit was put in at the bottom, nearest the source of heat, and the moist air driven from it through the trays of partially dried fruit above. In such towers, the air often had its temperature so much lowered before reaching the top of the stack that a part of the moisture carried by it was deposited upon the fruit in the upper trays. In the tunnel this may be entirely avoided by making the tunnels not more than 20 feet in length, and the time required for drying is very materially shortened with a corresponding improvement in the quality of the product.

When the plant is operating, fires are kept going continuously in the furnaces and trays of fresh fruit are inserted at the upper end of the tunnels as they are prepared. During the day, tunnels will usually be kept full to capacity by the replacement of the finished trays, as rapidly as they are withdrawn, by trays of green fruit, which necessitates the occasional shifting downward of the partially dried fruit to make room at the top. In the afternoon, before the employees cease work for the day, all other work may be stopped and a sufficient number of trays filled to replace those which will become dry during the night. These are stacked near the tunnels. It is the duty of the night man to keep up the fires, to remove such trays as become dry, to keep the unfinished trays compactly together in the lower portion of the tunnel, and to put in fresh fruit as room is made for it. This method has many advantages; it prevents the overheating and scorching likely to occur when the tunnels are gradually

emptied during the night; it utilizes all the heating value of the fuel burned, and it gives continuous operation at full capacity, hence at a lower cost.

Nothing will aid more in the rapid and economical drying of the fruit than constant attention to the ventilation. The air intakes into the furnace room must be adjusted anew with every change in the force and direction of the wind, and the damper in the ventilating shaft must be at one time widely open, at another almost closed. The plant can not be left in charge of a man who is either careless or unintelligent, he must understand clearly that it is just as much a part of his duty to maintain a vigorous draft through the tunnel as it is to keep the temperatures shown by the thermometers in the tunnels constant, and that failure in either of these respects results in slower drying and an inferior product of greater cost. Consequently, the men in charge of drying rooms should be the most intelligent and capable employees about the establishment. If there is any difference, the best man should be selected as night man, since the greater humidity and lower air temperatures prevailing at night make the task of securing satisfactory drying during that period more difficult than in the day. Once the men are selected and put to work, they should be held responsible for the management of the drying rooms, and no interference by others should be attempted or tolerated. "Many cooks spoil the broth" is a proverb never more true than when applied to the ventilating and heating of an evaporator.

THE CARSON-SNYDER "ALL PURPOSE" EVAPORATOR

In some of the smaller "box" evaporators in household use thirty years ago, the fruit was spread on a series of trays, and a current of warm air was driven horizontally across each tray from one side, escaping at the other, instead of being forced vertically upward thru the entire series, as is the case in the tunnel evaporator. This principle was first applied to the construction of a commercial evaporator in a patented machine called the Charlotte evaporator, and was later used in the Carson evaporator. This evaporator consisted

essentially of two tunnel-like chambers, one on either side of a central hot air chamber, which was situated directly over a furnace. Trays were pushed into these chambers along runways, as is the case in the tunnels, but the cleats forming the runways were so arranged that the trays were several inches lower at the side next the central warm air chamber. Slits in the wall admitted the hot air at the inner side of the trays, it passed horizontally over the trays to the opposite edge, and escaped through a second series of slits into a ventilating shaft. Professor U. P. Hedrick describes and figures such an evaporator in a publication to which reference has already been made, stating that it was in 1897 the most generally used type of evaporator employed in drying prunes in the state. The reports of the Oregon State Board of Horticulture at about this time contain incidental references to the Carson evaporator as an efficient and satisfactory prune drier, but it had some defects which led to its gradual replacement by the tunnel drier of the type first described.

Mr. D. A. Snyder of the Dayton Evaporating and Packing Company, Dayton, Oregon, is an exceptionally successful evaporator of some thirty-five years' experience, and operates a large plant in which he dries not only apples, prunes, and berries, but also a wide variety of vegetables. While some of the basic principles employed in the construction of his drier are identical with those of the Carson evaporator, Mr. Snyder worked them out independently, and as a result of years of study and experimentation he has devised so many improvements upon Carson's plan and has so increased both the efficiency and the economy of operation of his plant that he deserves chief credit for the development of what I shall call the Carson-Snyder "All-purpose" evaporator.

Mr. Snyder's plant has two independent drying units, each with its own heating system. Each of these units is two stories in height, and as the construction and arrangement of these differ materially, they must be separately described. The lower story of each unit has a central hot air chamber, situated directly over the furnace. This chamber is without a floor, and is warmed by heated air rising from the furnace

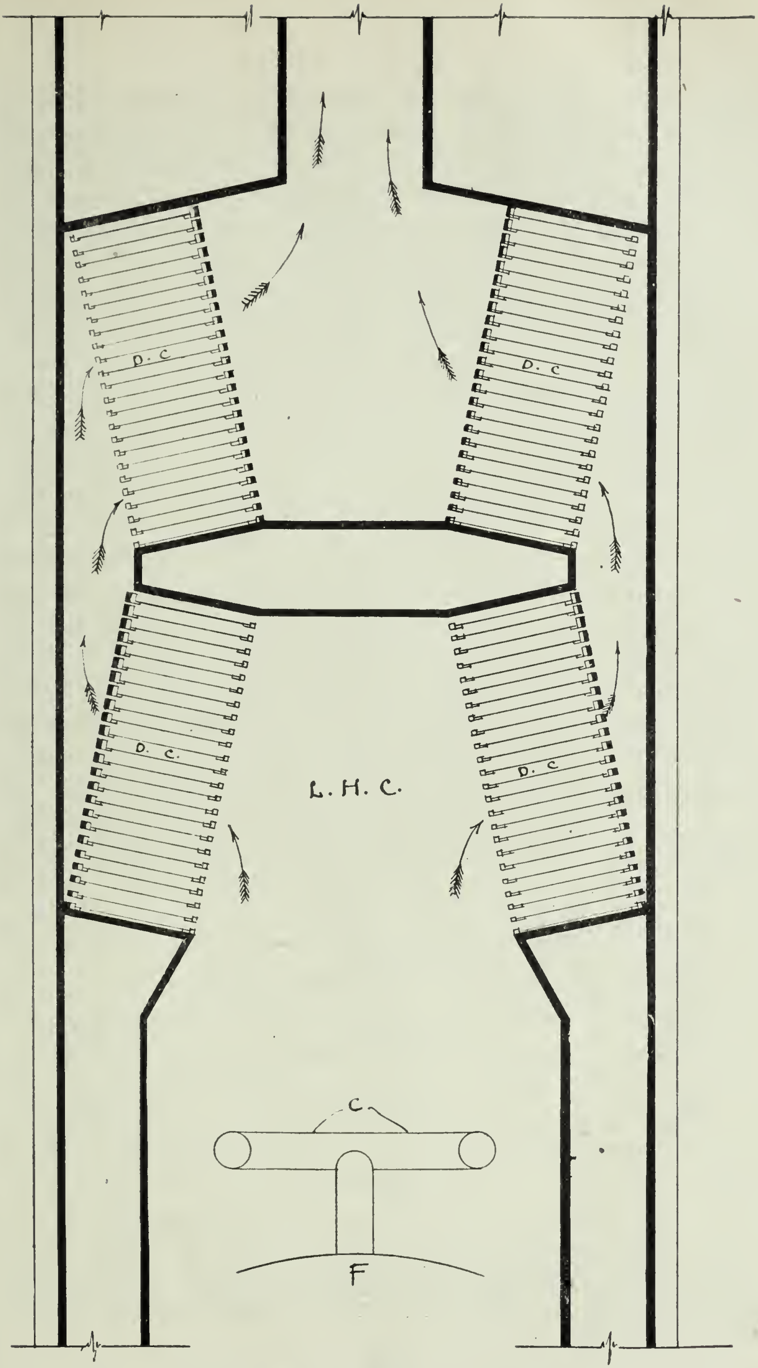


Fig. XXII. Sectional end view of one unit of the Carson-Snyder evaporator. F., furnace. C., coils of piping. L.H.C., heating chamber. D.C., lower drying chamber. D.C., upper drying chamber. V., ventilator shaft. Direction of movement of heated air indicated by arrows.

room below it. This hot air chamber is 18 feet in length, 7 in height, 7 in width at bottom and 4 feet in width at the top, and is continuous below with a space over the furnace. On either side of the hot air chamber is a drying chamber in which the trays are placed. Each of these drying chambers is 18 feet in length, 7 feet in height, and 2½ feet in width. The walls, instead of being vertical, are inclined toward the heating chamber, which is thus made 3 feet narrower at top than at bottom. Each drying chamber has 22 slat runways extending through its length, made of ½x1 inch slats nailed on edge to the studding. These slats are 3½ inches apart from center to center, and are so arranged that the outer edge of each tray is 6⅝ inches higher than the inner side. As the trays used are 1 inch in depth, there is an interval of 2½ inches between the top of the fruit in one tray and the bottom of the tray above. The inner wall of the tunnel, next to the hot air chamber, is built of 1 inch slats, which have intervals of 2½ inches between them, and these slats are so spaced that the upper edge of each slat is just flush with the top, while its lower edge is of course flush with the bottom, of the corresponding tray. The 2½ inch spaces between trays are thus freely open to the hot air chamber. On the outer side of the drying chamber, the wall is also built of slats, but the intervals between these become progressively

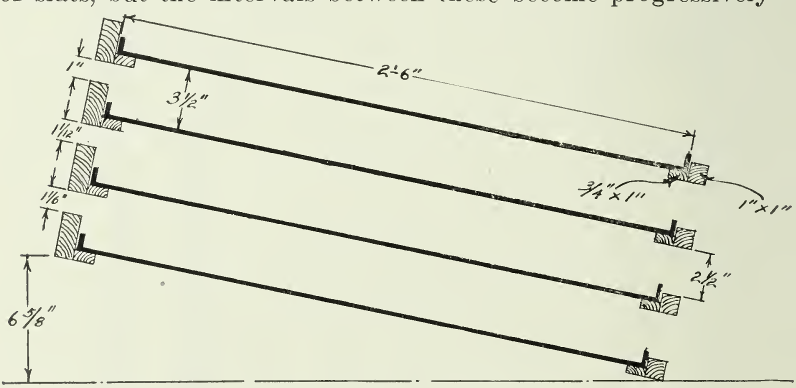


Fig. XXIII. Detail of portion of drying chamber of Carson-Snyder evaporator, showing inclination of trays toward air inlets at right. Graduated air exits, each one-twelfth of an inch wider than that above it, at left.

wider from above downward. Above the upper tray of the series the interval between slats is only 1-12 inch in width, above the next it is increased to 2-12, above the next to 3-12, and each successive interval is wider by 1-12 inch, so that the slit opposite the outer edge of the lowest member of the series of 22 trays is 1 11-12 inches in width.

Warm air rises from the furnace room into the hot air chamber and thence passes laterally through the openings in the walls into the drying chambers. Since there is at the opposite side of each tray a slit opening into a space outside the outer wall of the drying chamber, the air moves laterally across the face of the inclined tray and escapes into this space intead of rising through the trays above. The tendency of the warm air to rise to the top of the hot air chamber before passing laterally over the trays is corrected by making the inlets into the drying chamber all of the same width, while the outlets therefrom are successively wider from above downward, as already described. (See Fig. XXIII.) A very uniform distribution of the warm air is thus secured, the temperatures on upper and lower trays of the series differing only by two to five degrees. Consequently this evaporator differs fundamentally from the tunnel type in that all the fruit in any pair of chambers is kept at a uniform temperature.

The second story of each unit has a pair of drying chambers of identical size, construction, and capacity with the lower pair, but differing from them in that they are inclined outward instead of inward, and in that the outer wall has uniform air inlets 2½ inches wide between trays while the inner wall has the graduated slits for the exit of air. The warm air, after its passage through the lower drying chamber, passes into a space between the drying chamber and the solidly boarded, vertical outer wall of the unit. This space is freely open above into the space between the upper chamber and the vertical wall. Consequently, the warm air escaping from the lower drying chambers rises in this space, passes from it into the upper drying chambers, where it flows across the inclined trays to escape through the graduated slits into a central space from which a ventilating shaft carries it through

the roof. Since the central hot air chamber and the drying chambers of the first story are solidly ceiled with matched lumber, while the second-story drying chambers and the space at the base of the ventilator shaft have a tight floor, air can pass from the heating chamber to the ventilator only by passing over the trays. The whole of this ingenious arrangement will be readily understood from an examination of Figs. XXII and XXIII.

The upper drying chambers are of course much cooler than the lower ones, the difference averaging about 25 to 30 degrees. Consequently the time required for drying apples, which is 8 to 12 hours in the lower chambers when these are kept at 155-160 degrees, is lengthened to practically twice this time in the upper chambers, where the temperature ranges around 130 degrees. Mr. Snyder says that in so far as he is able to determine, the upper chambers turn out a product which is in every respect as desirable as that from the lower ones.

As previously stated, Mr. Snyder's plant consists of two two-story units, each having four drying chambers. Each chamber has a capacity of 22 tiers of 6 trays each, each tray being 30x36 inches in outside dimensions. Each chamber has therefore an approximate drying area of 990 square feet, or 7920 square feet for the eight chambers. Of this area, one half will dry apples in 12 hours or less, the remaining half in 24 hours, with a proportionate difference for other fruits and vegetables. The trays have a capacity of about 20 pounds of apple slices each. When operated continuously with the tunnels always full, the plant has a capacity somewhat in excess of 600 bushels or 15 tons of apples daily, but this is not the actual working capacity, as the trays emptied during the night are not re-filled until work at the parers is begun next morning. Loganberries are spread more thinly on the trays so that the drying chambers when filled carry six tons of fruit, which requires 15 to 24 hours in the lower and upper chambers, respectively. About 18 tons of prunes are required for one charge, and the time occupied in drying is 24 hours in the lower and 48 hours in the upper chambers.

A wide variety of fruits and vegetables have been dried in this plant which is located in a region which produces loganberries, raspberries, blackberries, prunes, peaches, apricots, cherries, apples, and a considerable variety of vegetables as potatoes, beans, carrots, onions, cabbage, and celery, and the plant annually dries all of these in some quantity. The company has built up a considerable business in the drying and blending of vegetables for soup, so that the plant is in operation for a large part of the year.

The furnaces are built of fire brick, and extend back for the entire length of the drying chambers, with a width of 6 feet. Cordwood is burned as it comes from the forest, hence comparatively little time is consumed in firing and one man can keep the fires going and look after the drying chambers, with occasional assistance when the fruit is being inserted or withdrawn.

Each furnace is enclosed by brick walls which extend up to the floor of the lower drying chambers, enclosing a space over the furnace 18 feet long, 9 in width, and 11 in height. In this space there are two tiers of pipe, one above the other, to increase the radiating surface.

Movement of air through the system is secured by a series of openings in the side walls which enclose the furnaces. These openings are 12 or 15 in number; each made by leaving out a brick in building the wall. They appear to the writer to be entirely too small to permit adequate circulation of air, and it is certain that more rapid drying would be secured were the openings increased two or four-fold in area. Since the air does not pass through a series of trays as it does in the tunnel evaporator, there is not the same necessity for rapid circulation to prevent the saturation of the air with moisture, but its sluggish movement results in greater reduction of temperature and consequently in slower drying in the upper chambers.

This system of drying has a number of features which very strongly commend it. The most objectionable feature of the tunnel evaporator, namely, that the fruit in the upper portion of the tunnel is surrounded by nearly saturated air at a tem-

perature many degrees lower than at the bottom of the tunnel, is entirely avoided. The objectionable features of the Charlotte and Carson evaporators have been eliminated, and their desirable characters very materially improved and perfected. The heat produced by the fuel is very fully utilized, and the plant has the advantage that the drying units can be made of any desired length, provided the size of the furnace and the radiating surface of the piping be correspondingly increased. The very satisfactory quality of the apples, prunes loganberries, and vegetables produced is evidence that the method can be successfully used in drying any fruit or vegetable material which it might be desired to evaporate. For these reasons, the Carson-Snyder type of evaporator ought to receive careful consideration at the hands of those who desire a general purpose evaporator capable of handling a wide variety of fruits. When such a plant is built it should be equipped throughout with labor-saving power-operated machinery, and as the arrangement of the drying chambers one above the other necessitates transfer of fruit from floor to floor, an elevator and wheeled trucks for moving fruit in quantity will eliminate a very large expenditure of time and labor. There should be spreading tables on both drying floors in order that fruit may be delivered in quantity and placed on trays near the chamber in which it is to be dried. It seems feasible to the whiter to eliminate the handling of the trays individually in the drying chambers by substituting wheel trucks carrying an entire tier of trays, which could be handled as units.* Since the temperatures at bottom and top of a prop-

*Such a truck need be merely a substantial base with small, heavy wheels, with a framework for carrying trays equal in height to the height of the drying chamber. The framework should be somewhat narrower than the trays, which should project at either side, and the cleats supporting the trays must be accurately spaced to correspond to the spacing of air inlets and outlets in the drying chamber. Trays should be inserted at the sides and kept in place by vertical strips at the end of the frame. When rolled into the drying chamber, the projecting edges of the trays should be just above and should overlap the runways on the inner walls of the tunnel, thus insuring lateral movement of the air. If substantially built and properly braced to prevent warping, such trucks would soon pay for themselves in the saving of time and effort they would accomplish.

erly constructed and ventilated drying chamber are practically identical, the rate of drying throughout should be uniform, and a truck need not be unloaded until it has been removed and transferred to the curing room.

It may seem to the reader that undue space is given to discussion of labor-saving devices and of minor economies of operation for eliminating hand labor wherever possible. That this is not done without good reason will perhaps be apparent when it is recalled that the evaporation of fruit is a business in which the margin of profit is relatively narrow and that profits depend upon the handling of large volumes of raw material, while the period in which work can go on is made a short one by uncontrollable climatic conditions. Anything which saves time or reduces hand labor increases output and lowers cost, hence widens the margin of profit. The writer has made an analytical study of a number of unsuccessful plants as well as of many very successful ones and can say that success is not so much dependent on the particular type of evaporator employed as upon economy of time and labor through the employment of machines. The rock upon which at least eight out of ten unsuccessful enterprises are wrecked is the rock of too much hand labor. The plant in which the employees spend the day in the backbreaking task of carrying boxes of fruit across the floor and up and down stairs or in turning a handpower slicer or hand parers, each of which needs two trimmers to do what the machine should in large part have done, will be a place in which employees will shirk and save themselves. It must compete with the plant in which this heavy time-consuming work is done by power, and the ultimate result will be that operation is carried on at a loss. The adoption of such labor-saving devices as are here suggested, and the constant taxing of one's ingenuity to improve them and to develop others, will do more than anything else to insure a permanent business with satisfactory profits.

PREPARATION OF MATERIAL FOR DRYING ON TRAYS

The general methods for the washing, paring and slicing, bleaching or steaming of the various fruits and vegetables for

drying, are of course identical, no matter what type of drier may be employed, and have been discussed on page 42. What is said here relates to the arrangement of spreading tables and the actual work of placing the fruit upon trays in readiness for drying in a tunnel or all-purpose evaporator. The spreading table should be located as closely as possible to the tunnels or drying chambers, in order to avoid the needless labor of carrying loaded trays by hand, and should be of the same width as the trays used and high enough to permit the spreader to stand erect. It should be well lighted, empty trays should be conveniently stacked at one end, and there should be room for placing berry crates or lug boxes filled with fruit upon the table in order that the spreader may not be forced to lift them as they are needed.

If possible, women should be employed as spreaders, and the same operator should be kept at the work through the season, as it requires a deftness and quickness which is only acquired by constant practice. In handling berries, the spreader inverts a box or other vessel of fruit over the tray and by gentle movements of the fingers spreads it to a uniform depth, making no attempt to pick out crushed or green berries, stems, or other debris, which can be picked off the trays when the fruit is dry without injury to the perfect stock. When spreading halved peaches or apricots, the spreader must turn each piece with the stone cavity uppermost and make a single, closely-placed layer over the tray. Material cut in clices, as apples, potatoes, or carrots, may be spread to a depth of one or one and one-half inches, but the spreader must be careful to separate any slices which adhere together like a stack of coins in order to secure evenness in the drying. Prunes must be spread in a single, closely-placed layer, as is the case for pumpkin cut into cubes, while such material as cabbage and onions, which lie loosely upon the trays, may be spread to a depth of two or two and one-half inches.

If the spreader employs proper care in spreading fruit to an uniform depth and in separating masses which cling together, it will be unnecessary to stir the material until nearly dry, when the trays may be examined, any compact, slowly drying

portions loosened up and any thin, rapidly drying spots more thickly covered. Some operators make a practice of combining the partially dried fruit from two or even three trays upon a single one, as soon as it can be transferred without crushing, but the air moves slowly through the thicker layers and it is certain that the increase in time required offsets the gain in capacity. This is also the case in those tunnel driers in which the trays are heavily loaded; since the air must move upward through the fruit, overloaded trays hinder its circulation, keep the upper portion of the tunnel cooler than it should be, and actually decrease the daily output instead of increasing it.

The Preparation of Prunes for Drying. Prunes require special treatment preparatory to drying, the general methods employed are described in the papers by Hedrick, Balmer, Dosch, Allen, and Brown and Bradford, already cited in the section on the literature of evaporation. While there is substantial agreement as to the general methods employed, there are endless differences of opinion as to minor details, and the following statement presents what may be fairly considered as the prevailing methods in use among driers of prunes.

It may be said at the outset that any plum or prune which has a high sugar content and possesses a thick, tough skin can be successfully dried, while it is scarcely advisable to attempt drying such thin-skinned varieties as the egg plum, since such fruits burst and drip badly while drying. Furthermore, such prunes as the Golden Drop do not require treatment with lye, but must be passed through the bleacher in order to preserve the color. Silver prunes require both lye dipping and bleaching, while the Prune D'Agen, French prune, and Italian or Fellenberg prune do not require bleaching, but must be dipped in lye. For those prunes which require bleaching, an exposure of ten to fifteen minutes to the fumes of sulphur is usually adequate; if bleaching is done in an apple bleacher geared to pass the fruit through its length in thirty to forty minutes, the amount of sulphur burned may be reduced to one half or one third the amounts which would otherwise be employed.

The drying of prunes may be begun as soon as the fruit is market ripe, but most operators prefer to allow the fruit to remain on the tree somewhat longer and a few permit it to fall, going over the orchard daily and collecting the fruit from the ground. The most economical method for gathering the fruit is to spread bagging or tarpaulins beneath the trees, shake them vigorously, and collect the fruit into lug boxes from the cloths. Two or three gatherings made in this way will clear the fruit from the trees much more quickly than hand picking with the further advantage that the fruit will be much more uniformly ripened and will consequently dry more evenly, giving greater yield and more uniform quality of dry product.

The lye solution used is most commonly made by dissolving concentrated lye in water at the rate of 1 pound for each ten gallons. The solution is kept a few degrees below boiling point when in use, by keeping it in a large kettle or galvanized tub placed upon a heating stove. Convenient dipping vessels are made by cutting out one side of an ordinary five-gallon oil can, punching the sides and bottom full of holes—which should be made from the inside in order that the rough edges may not injure the fruit—and adding a wire handle. Such vessels may be made in quantity and used as picking baskets, or the fruit may be transferred into them from lug boxes as it is dipped.

The object of the lye dip is to cause "checking" or cracking of the skin, thus hastening the subsequent drying, and the lye should be allowed to act no longer than is necessary to produce checking; prolonged action destroys the skin and thus causes the fruit to drip badly. Also, well ripened fruit checks much more quickly than immature or market ripe fruit. At the beginning of the season, a dip of 30 to 45 seconds in a "standard" lye solution (1 pound in 10 gallons of water) will usually give the desired result; as the fruit ripens, the time must be progressively reduced or the solution diluted by adding water.

In dipping, the basket of fruit is lowered into the hot lye solution, moved gently up and down to hasten contact of the liquid with the fruit, and immediately transferred to a larger vessel or tank of fresh water, where the basket is moved about for a minute or two to assist in washing off the lye. It is then

transferred to the spreading tables, spread in a closely placed single layer on the trays, and placed in the drier.

EVAPORATOR MACHINERY AND EQUIPMENT

Paring Machines. Paring machines to be operated by power have been brought to a high degree of perfection, and there are several standard makes of practically equal merit on the market. Among such machines may be mentioned the "Pacific No. 2," the Goodell, the "Ranger," the "Improved Triumph"and the Coons. All these are heavy, well made, durable machines which stand up well under hard and continuous usage. The illustrations show the general plan of all such machines in that there are three forks; an apple is cored and discharged from one of these while that upon a second fork is being peeled, the operator meanwhile placing the fruit upon the third. While the claim is made by some makers that their machines have trimming attachments which make hand trimming unnecessary, it must be said that the writer has seen no machine which can do nore than reduce the work of trimming by two-thirds or one-half when working with good fruit, or by perhaps one-third when small, irregular apples are being peeled.

There are a number of good machines to be operated by hand; nearly every maker of evaporating machinery in the list given below makes a machine which has been proven satisfactory, but the use of such machines in a large plant would be a mistake.

Slicers. Several power slicers, among which may be mentioned the Boutell, the "Rochester," the "Ontario," the Evans, and the Goodell, are widely used and strongly recommended by users. Such machines are of two types, the under-cut, in which the knives which slice the apple pass beneath the fruit, and the overcut, in which the exact opposite is the case. A defect common to all overcut machines in so far as the writer is acquainted with them arises from the fact that the apple is permitted to roll somewhat before the knives, with the result that some fruits are sliced at oblique angles with the core hole or even parallel with it, while a

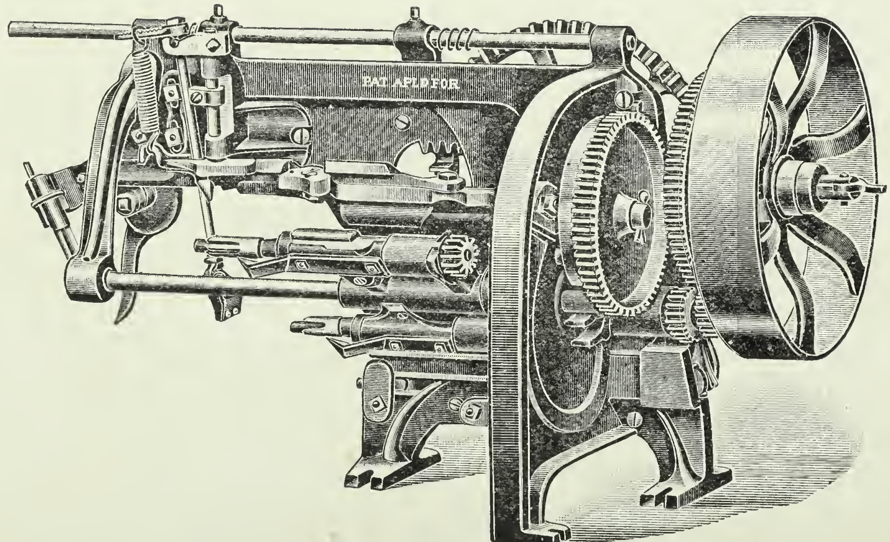


Fig. XXIV. A popular and efficient type of power parer.

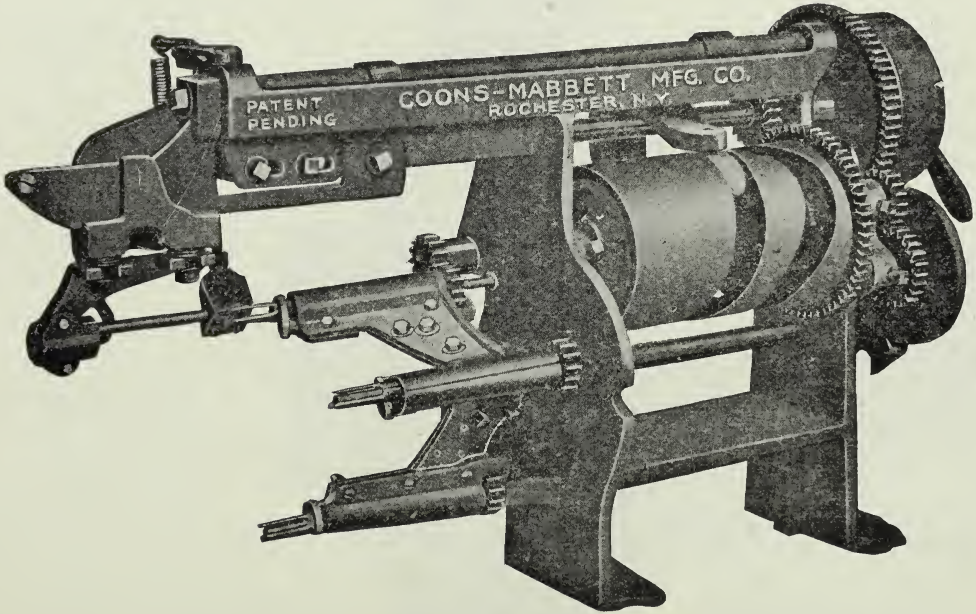


Fig. XXV. A power parer having an automatic trimming device.

larger percentage of slices are broken than is the case in the undercut machines. Most of the companies making power machines make also smaller machines to be operated by hand power.. The illustration represents a good type of undercut power slicer.

Graders. A good grader, separating the fruit into three or four sizes, is a necessity in every evaporator; a larger output per day will be handled by the parers and trimmers if fruit is separated into sizes before paring, adjustments of the knife heads to suit the particular size of fruit being handled can be made, and a better price will be obtained for the product if the

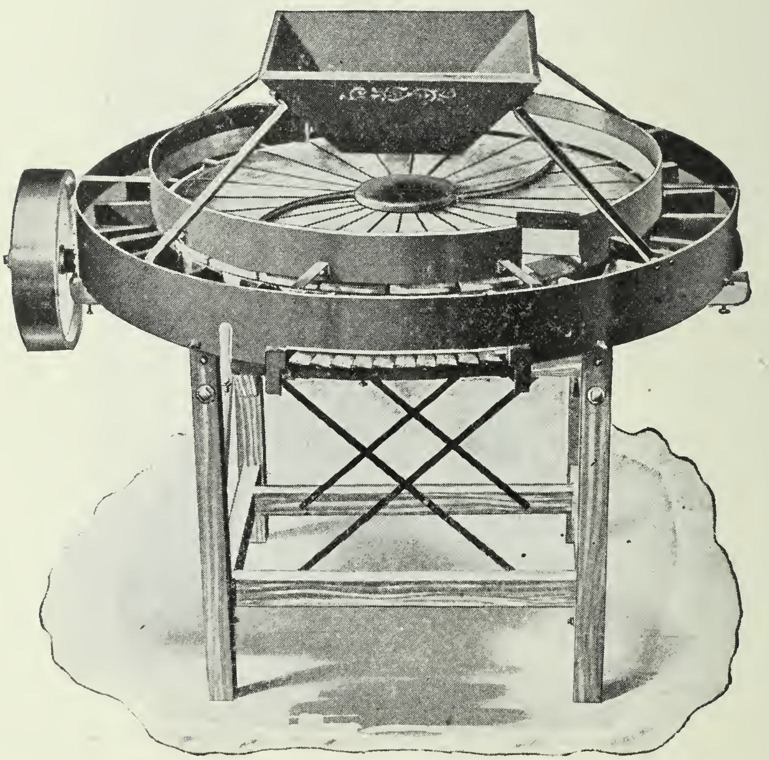


Fig. XXVI. An efficient under-cut power slicer of large capacity.

larger fruits are worked up together, since price depends to some extent upon size of rings. Since a grader is likely to be available as a piece of orchard equipment already in hand, no one should attempt to handle apples of all sizes indiscriminately mixed together.

Other Equipment. The construction of a good type of power bleacher has already been discussed. Any large wholesale hardware company can supply gearing, chains and other metal parts, and the wooden portions may be made by a good carpenter at a considerable saving over the prices charged by the supply companies. The same statement holds true of the paring tables, which can be built by any good carpenter. The horizontal conveyors employed for carrying pared apples and waste are simple slat-and-chain devices, running over wooden rollers, as is the conveyor through the bleaching box. The vertical conveyors are also of the slat-and-chain type, but have every third or fourth slat replaced by an U-shaped trough, having its sides made of slats and its bottom of a 4-inch strip. The ends are closed and the trough is attached by one side to the chain. All wooden parts of the conveyors and bleacher can be made on the premises at a cost very considerably less than that of the complete equipment, since the necessary chains, shafting, and gearing can be purchased separately.

The following companies are manufacturers of parers and slicers, both for hand and power, of the most modern and efficient types:

Boutell Manufacturing Co.........Rochester, N. Y.
Coons-Mabbett Manufacturing Co...Rochester, N. Y.
Goodell Manufacturing Co...........Antrim, N. H.
Fruit Machinery Co......Ingersoll, Ontario, Canada
Evans and Company.................Medina, N. Y.

The following concerns are makers of conveyor chains, bleacher gears and castings, hangers, shafting, packing presses, and other evaporator accessories:

Link Belt Co....39th St. & Stewart Ave., Chicago, Ill.
Hallauer & Phillips..................Webster, N. Y.
Haverstick & Company.............Rochester, N. Y.
W. A. Trescott Co...................Fairport, N. Y.
Berger & Carter Co............San Francisco, Calif.
Chain Belt Co......................Milwaukee, Wis.
Michigan Sprocket Chain Co...........Detroit, Mich.
Ewart Works,
Michigan St. & Stewart Ave., Chicago, Ill.

The following firms are makers of wood-burning "hop stoves" of sufficient size and weight to be used in heating evaporators:

Yakima Hardware Co.........North Yakima, Wash.
Union Iron Works.................Spokane, Wash.
F. S. Lang Mfg. Co..................Seattle, Wash.

TEMPERATURES TO BE EMPLOYED IN DRYING

It must be said at the outset that no chemical studies of the changes occurring in fruits and vegetables in the process of drying have been made, and that we consequently have no exact knowledge as to the extent to which loss of flavor, destruction of sugar, or other chemical changes occurring during drying can be controlled by controlling temperature. The recommendations made here are simply such as have been worked out by practical evaporators, and are in agreement with the practice of the great majority of such workers. Briefly stated, the principles involved in determining the temperatures to be employed are these: The fresh, water-filled material must be kept at a moderate temperature for several hours at the outset of drying, or the rapid expansion of the cell contents will break down cell walls, resulting in loss of sugar and other solids by dripping. As soon as sufficient loss of water to cause considerable shrinkage and "wilting" of the material has occurred, the temperature may be increased somewhat, and this increase may go on progressively as the material becomes dryer. There is in every case an upper limit beyond which the temperature may not be carried without producing

two undesirable results; overheated material may be charred and a portion of the sugar converted into caramel, or the outer surfaces of the pieces may be dried while the central portions still contain so much moisture that subsequent spoiling will occur. The temperatures here recommended for use are such as have been found safe in that they permit drying to be carried on as rapidly as possible without injury to the material; they differ in the case of different fruits and vegetables by reason of differences in the physical structure and water-content of the various materials.

TABLE I

Temperatures to be employed in drying various materials.

Material	Initial temperature degrees	Finishing temperature degrees	Time required for drying on kiln, hours	Time required for drying on trays, hours
Apples, in rings	140-145 for 4-6 hrs.	160-175	16-24	7-14
Apples, quartered	140-145 for 6-8 hrs.	160-175	18-24	10-14
Apricots, halves	125-130 for 3-4 hrs.	165-180	10-16	6-12
Peaches, halves	125-130 for 3-5 hrs.	165-180	10-16	6-12
Peaches, sliced	140-145 for 4-6 hrs.	165-175	12-15	7-12
Pears, quartered	130-140 for 3-4 hrs.	150-165	16-20	12-16
Cherries, whole	125-135 for 4-5 hrs.	150-170	12-15	7-10
Blackberries, raspberries or loganberries	125-130 for 3-5 hrs.	150-180	8-14	7-12
Prunes, Italian or French	120-135 for 4-8 hrs.	160-185	-	24-36
Green corn	130-145 for 3-4 hrs.	165-190	12-16	8-12
Green beans or peas	125-140 for 2-4 hrs.	160-180	10-15	6-12
Tomatoes, pared, whole	115-125 for 2-4 hrs.	160-170	8-12	6-10
Potatoes, white, sliced	130-145 for 3-5 hrs.	175-185	16-24	7-14
Potatoes, sweet, sliced	125-140 for 3-4 hrs.	165-180	12-18	6-12
Carrots, pared and sliced	140-150 for 3-5 hrs.	175-185	12-18	7-14
Beets, sliced	130-140 for 2-4 hrs.	170-185	16-20	7-12
Parsnips, pared and sliced	140-150 for 3-4 hrs.	175-190	15-20	6-10
Cabbage, sliced	130-145 for 2-3 hrs.	175-185	12-16	7-12
Onions, sliced	120-130 for 2-4 hrs.	160-170	10-16	5-12
Pumpkin, 1½-inch cubes	135-150 for 3-5 hrs.	175-190	15-20	7-12
Rhubarb	145-155 for 2-3 hrs.	160-170	10-16	6-12

It will be noted that there are wide variations in the temperatures recommended, both for beginning and finishing the drying process, and also in the statements of time required. This is for the reason that the temperatures which it is permissible to employ, and consequently the time required for drying, depend absolutely upon the ventilation of the drier. If a vigorous movement of air can be kept up at all times, the drying of any given material may be begun at the highest temperature named under "Initial temperatures" in the table and the heating gradualy increased until the highest figure given under "Finishing temperature" is reached toward the end of the process, without danger of injury to the product. But if circulation of air can not be controlled, these temperatures would cook the material instead of drying it, and the whole process must necessarily be conducted at the lower temperatures suggested in the table, with the result that a considerably longer time will be required. In two kilns of identical size, loaded to the same depth and heated by the same type of furnace, it may be possible to start apples in one kiln at 145 degrees, beginning to increase this after 4 hours and finishing at the end of 16 hours at 175-180 degrees, while the other kiln must be started at 135 degrees, held at that temperature for 6 hours, then very gradually increased to not more than 160 degrees toward the end of the 24-hour period required to accomplish the drying, merely because of differences in the air circulation in the two plants. Hence the capacity of any given plant depends first upon provision of adequate air intakes and efficient ventilating shafts and secondly upon constant, intelligent attention to atmospheric conditions and suitable adjustments of air inlets and ventilators.

RELATION OF TEMPERATURE OF THE AIR TO ITS MOISTURE CARRYING CAPACITY

It must not be forgotten that the capacity of the air to carry moisture is a function of its temperature, and increases rapidly as the temperature is increased. How significant this fact is may at once be seen from consideration of the fact

that 1 cubic foot of air at the freezing point can absorb 1-160 part of its weight of water, and that the water-absorbing capacity is doubled with every increase of 27 degrees in temperature. This is shown in the following table:

Temperature	1 cubic foot of air can absorb
32 degrees	1-160 its weight
59 degrees	1-80 its weight
86 degrees	1-40 its weight
113 degrees	1-20 its weight
140 degrees	1-10 its weight
167 degrees	1-5 its weight
194 degrees	2-5 its weight
221 degrees	4-5 its weight

If we disregard the expansion of air with increasing temperature, which we may do since it amounts to only 1-490 of the volume for each degree rise of temperature, it will be seen that air raised from 86 degrees to 167 degrees has had its moisture-carrying capacity increased eightfold, whereas if the temperature be raised to 140 degrees the moisture-carrying capacity will be increased only four-fold. It is, therefore easily seen that in drying any substance not easily injured by heating choice may be made between the use of a very large volume of air moderately heated or a much smaller volume of air raised to a higher temperature. The fact that under ordinary conditions the rate of movement of the air over fruit can not be brought under the control of the operator necessitates the use of higher temperatures in order to bring the time required for drying within reasonable limits.

MOISTURE CONTENT OF EVAPORATED FRUITS AND VEGETABLES

The only legislation specifying permissible moisture content in evaporated products is found in the agricultural laws of New York, which define "standard evaporated apples" as apples containing not more than 27 per cent of water as determined by drying for four hours at the temperature of boiling water. This law has been adopted by a number of states and also by the Joint Committee on Definitions and Standards of the Bureau of Chemistry, U. S. Department of

Agriculture, as a legal standard for moisture in evaporated apples. It has been conclusively demonstrated that this standard is too high; apples containing 27 per cent of moisture deteriorate rapidly in warm weather outside of cold storage, and great injury has been done the market for evaporated apples, both in the Southern states and abroad, by the spoilage of such fruit in transit or in the hands of purchasers after its receipt. Hence there is a general demand, both from consuming territory and from manufacturers of evaporated apples, for a law fixing the permissible moisture content of evaporated apples at a figure not higher than 25 per cent, and many manufacturers favor 24 per cent. There is a strong probability that a ruling of the Committee on Definitions and Standards, fixing the legal moisture content for apples at 24 or 25 per cent, may shortly be made. Whether such ruling is made or not, it is positively known that apples dried to 24 per cent moisture may be kept in common storage and at ordinary living-room or outdoor temperatures for long periods without danger of spoilage, that such fruit may be shipped into tropical or sub-tropical climates as well as into temperate regions with no danger of deterioration, and that no injury to appearance, flavor or quality results from carrying it to the lower moisture content. Consequently, every operator of an evaporator should adopt 25 per cent as the maximum above which he will not allow the moisture content of his apples to go, and such a rule will yield substantial dividends in the greater favor shown by the consuming public.

There are no laws regulating the moisture content of other evaporated products than apples; such standards as obtain among operators have been set by custom and through finding that a given product required drying to a definite point in order to insure against subsequent deterioration. There are consequently considerable variations in the practice of evaporators in different regions of the United States, the general practice in the Southern and Southwestern territory being to reduce all materials to greater dryness than is the custom in the Eastern districts. The following table gives average yields per ton of fresh material and permissible

moisture contents for the various fruits and vegetables which the evaporator is likely to handle.

TABLE II

Yields of various fruits and vegetables per ton fresh material.

Material	Yield per ton, pounds	Moisture content of dry product, per cent
Apples, white stock varieties	250-260	25
Apples, dark stock varieties	260-285	25
Apricots, halves	350-400	26
Peaches, halves	225-250	22
Pears, quarters	270-300	24
Cherries	400-450	24
Blackberries	380-400	18
Raspberries, Cuthbert or Shaffer	400	18
Raspberries, Gregg or Ohio	440-475	18
Loganberries	340-370	18-20
Prunes	600-675	22
Green corn	480-520	15-17
Green beans	275-325	16-18
Green peas	400-475	15-18
Tomatoes	150-200	15
Potatoes, white	475-525	16-18
Potatoes, sweet	575-650	17-19
Carrots	275-320	16-18
Beets, garden	300-320	17-20
Beets, sugar	340-400	17-20
Parsnips	250-300	16-18
Cabbage	240-275	17-20
Onions	240-300	16-20
Pumpkin	250-325	18-20

In amplification of this table it may be said that the so-called "white stock varieties" of apples comprise the Baldwin, Spitzenberg, Ben Davis, Gravenstein, and Winesap, all of which yield a very white product desired by the concerns which re-pack dried fruit in small cartons for the high-class grocery trade. The "dark stock varieties" include such apples as Delicious, Jonathan, Black Twig, Rhode Island Greening, Rome Beauty, Stayman Winesap, Yellow Newtown, Grimes Golden, Wagener, Gano, Missouri Newtown, and the Russets. All these, by reason of possessing a higher sugar content than the white stock group, give a somewhat higher yield of dry product, which is not so white but has a higher food value than that of the group first named. As examples

of actual yields for some varieties, the following figures, based upon determinations made upon apples grown in various districts of Washington, Oregon, and Idaho, may be of interest.

	Dry fruit, per ton, pounds	Moisture content, per cent
Arkansas Black, culls	255	22.6
Arkansas Blick, C grade	256.8	22.9
Ben Davis, culls	250.8	24.4
Ben Davis, culls	261.6	23.9
Ben Davis, C grade	262.4	22.9
Rome Beauty, culls	258.7	23.1
Winesap, culls	254.8	23.8
Wagener, culls	292.6	24.6
Wagener, C grade	267.2	22.3

It may be noted that all these samples were dried below the recommended moisture content of 25 per cent and that notwithstanding this fact, the weights run well above 250 pounds in all but two samples. The boxes of fruit from which samples for moisture determination were taken have been stored on an open shelf in the writer's laboratory since the moisture determinations were made, sixteen months ago, and have undergone no deterioration during that time.

DETERMINING WHEN THE PRODUCT IS PROPERLY DRIED

Material should be removed from the kiln floor or drying trays when it still contains slightly more moisture than the finished product is to have. The ability to judge accurately as to when any fruit or vegetable has reached the proper condition for removal can only be gained by experience, but some general statements may be made. Apples which are sufficiently dried for removal should be so dry that it is impossible to press water out of the freshly cut ends of the pieces, but should be sufficiently elastic not to break when the piece is rolled into a cylinder. When a mass of slices are pressed firmly into a ball in the hand, they should separate at once when released. The surface should be soft and should adhere slightly to the fingers, leaving the hands "sticky" after handling them. Occasional slices will, of course, have more or less than this amount of moisture, but the general condition of the fruit should be that just described.

Properly dried prunes have a firm, elastic texture and are free from stickiness, the flesh is free from the pit, uniformly yellow in color throughout, and does not exude moisture on tearing and pressing with the fingers, while the skin is smooth and bright. Cherries ready to be taken from the drier have the same physical character, but should be dry enough to rattle a little when stirred, since it is better to over-dry the fruit and subsequently equalize the moisture in the curing room than to take it off when insufficiently dried. Peaches and apricots should be dry enough not to moisten the hand when a handful is strongly pressed together, and should separate again when squeezed into a ball, while the thinner edges of the skin should be quite hard and the juice contained in the stone cavity should have dried into a firm, solid mass. Berries should be allowed to dry until no moisture can be forced out of a handful by vigorous pressure, and until the dryer berries rattle a little when the fruit is stirred. For pears, cut into quarters, the tests described for apples hold equally good, and the pieces should show uniform drying all the way through when cut across and examined.

These suggestions, as would be the case with any others which could be given, will leave the amateur seriously in doubt as to when his fruit is properly dried, since ability to judge correctly of the condition of the material from its apearance and texture can only be acquired by experience. It is an excellent plan for the beginner to check his judgements of his fruits by providing himself with an accurate balance, weighing the fresh fruit from which the slices placed upon a given tray or a certain area of the kiln floor are made, and weighing the material again when he considers it sufficiently dried, with the table of yields given on page 91 as a guide. In every doubtful case it is better to continue the drying until no doubt remains, since insufficiently dried fruit must be returned to the drier while that which is over-dried can be conditioned in the curing room.

The fruit is taken directly from the kilns or drying trays to the curing room. If only a single fruit is being dried, the

curing room may be an enclosure with a tight floor, shades to exclude light, which would cause darkening of the fruit, and screened to exclude insects; in which the fruit is piled directly upon the floor to a depth of one or two feet. If a variety of products are being dried, open-topped bins may be built against the walls of such a room, one for each product. Here the fruit undergoes an after-curing or "sweating" process, in the course of which the over-dried portions take on moisture from the wetter fruit with the result that the moisture content of the whole mass is equalized. To facilitate the process, the fruit should be thoroughly stirred with a wooden shovel once or twice a day. Apples, peaches, pears, apricots, or berries require two or three weeks to complete the sweating process, while prunes or cherries need at least twice this time but need be shovelled over only at intervals of two or three days. After the sweating is completed, the fruit may be packed for sale, or it may be allowed to remain in the bins indefinitely without injury if shielded from light and protected against the visits of insects. The curing room should be kept at the temperature of an ordinary living room, 60-70 degrees.

It is practically impossible to put into words any description of the appearance of the various vegetables which will be a safe guide for a beginner attempting to decide when the product is sufficiently dried. Potatoes, carrots, beets, parsnips, and root vegetables generally should be dried until the slices have lost the tough, leathery character of the partially dried material and break crisply when crushed together. Cubes of pumpkin should have the firm, elastic character of a block of rubber but should be uniformly dry throughout and should yield no visible moisture when cut open and pressed vigorously. Green corn, beans or peas should rattle audibly when stirred and should be quite firm and hard when pressed between the fingers, while the bits of cabbage or onion should break when strongly bent. The amateur will find that it is safest to weigh small lots of the raw material and to check the drying by these until he has acquired confidence in his judgments.

GRADING AND PACKING THE DRIED PRODUCTS

With regard to the packing of dried vegetables, it may be said that there are no established trade practices. While the drying of vegetables has been carried on by a few firms in widely separated parts of the United States for many years past, the total volume of material produced was small and found its market in Alaska or among owners of freight steamers. For the most part material intended for Alaska was packed in bags of 50 or 100 pounds each, while that packed for the marine trade was put up in tight tin containers of 10 to 50 pounds each. The present demand for dried vegetables comes from new purchasers representing foreign governments, and each of these will supply specifications as to the character and size of the containers which it is desired that manufacturers use. Persons intending to engage in the production of dried vegetables in a large way should first establish contact with purchasers and secure information as to packages desired before attempting to put up the product.

Grades for evaporated apples are much more clearly defined than are those for other evaporated fruits, with the possible exception of prunes, hence may be stated somewhat in detail.

The trade recognizes four standard grades of evaporated apples, which may be briefly defined. ''Extra Fancy'' is a name used to designate the highest quality fruit, and consists of very white fruit in complete rings of large size, with only a very small admixture—5-8 per cent at most—of broken pieces. It must be free of bits of skin and core ,and must be perfectly clean. ''Fancy'' is also a clean white stock without skin or core, but may consist of somewhat smaller rings with a somewhat larger proportion of broken pieces. ''Choice'' is on most markets, a slightly darker, somewhat golden stock made from apples of high sugar content, reasonably free of skin and cores, and with 60 to 70 per cent of the slices in perfect rings. ''Prime'' is a designation for fruit which, while fairly white, has more broken pieces, peel, or seed cells than are permissible in the ''choice'' grade, or which is reasonably free of these but is somewhat darker in color. A fifth grade,

called "middling" or by various other names, receives all fruit which has been so badly trimmed and cored that it can not be admitted to "prime," which contains too large a proportion of broken rings and chips, or which has been badly bleached and is consequently very dark in color.

The best evaporators make several grades of stock from the same lot of apples, by grading the fruit prior to peeling and slicing, and drying large and small fruits separately. When a power slicer is used, the separation into grades is carried further by dividing the chute from the slicer by partitions, so that the large slices from the center of the apple pass into one receptacle while the smaller slices from the ends pass into another and are separately dried. When packing begins, the fruit is again sorted over, the largest perfect slices being put together as extra fancy, those also perfect but made from smaller fruits going into fancy, while the smallest slices are put together into prime, and only the broken bits of ring, slices with adhering seed cells or skin, and pieces with other imperfections, along with badly bleached fruit, remain to fall into the lowest grade. Such care is well repaid by the higher prices which will be received for the perfect fruit of the upper grades.

In packing the fruit, wooden boxes containing 25 or 50 pounds are used for all grades above prime, while prime and middling are more frequently sacked in bags containing 50 or 100 pounds. A fifty-pound box is usually 22x11x10½ inches, while the twenty-five pound box is 18x9x9 inches, inside dimensions. These boxes are made with a loose side which becomes the bottom, not the top, of the box when it is filled. Packing is begun by "facing" the future top of the box with a layer of perfect slices of good size, which are laid in overlapping fashion, like the shingles on a roof, over the entire surface, after lining the box with paraffined paper which usually has a fancy lace edge. After the "facers" are in place, a second box of the same size but with both bottom and top removed is placed over the first one, and the fruit is packed in by hand until the desired weight is reached, when the box is transferred to the platform of a hand press, a board slightly

smaller than the inside dimensions of the box is placed on top, and pressure is applied until the fruit is forced down sufficiently to permit the bottom to be nailed on. The package should be finished by stenciling thereon the maker's name and address, with the weight, grade, and the variety of fruit from which the product was made. A guarantee covering these facts may advantageously be added.

In packing peaches or apricots, very little attempt to grade the product is made further than to pick out visibly charred or imperfectly trimmed pieces, and all sizes of fruit, of all degrees of perfection in appearance, are indiscriminately mixed together. Large, well-shaped, perfectly bleached pieces are selected as "facers," and the top of the box is covered with a double layer of these, which are then lightly pressed to make them retain position in the subsequent filling and pressing, which is conducted precisely as with apples.

Evaporated berries should be passed through a fanning mill fitted with a special screen, to remove bits of stem, leaves, and other foreign matter which could not be removed from the fresh berries. This screen also removes masses of soft berries which have adhered together. The container chiefly used is the fifty-pound box, which is filled without facing; a number of enterprising evaporators grade the product somewhat carefully and pack the better grades in one-pound paper cartons, bagging imperfect, crushed, and overheated berries together in 50-pound bags for sale at a lower price. There is no question that the evaporator who will give more attention to the grading and packing of loganberries and apricots, in particular, will find himself well repaid in the higher prices received for that portion of his product which goes to the Eastern and middle Western markets.

Evaporated cherries have thus far been produced only in very small quantities, and the same statement may be made of evaporated pears. Practically the entire product is packed in small cartons for the retail trade, and there is a good demand at prices which will substantially repay the additional cost of such packing.

Prunes should be graded into the various sizes prior to drying, as a very much more uniform product will be secured if all the fruits upon a given tray are of the same size. They should again be graded into the various commercial sizes—30-40, 40-50, 50-60—when packing begins. The fruit is "processed," "finished," or "glossed," as the process is variously termed, just prior to packing; the purposes of this treatment are to clean the fruit and give it a bright, glossy appearance and to render it somewhat more pliable in order that closer packing in the boxes may be secured. This may be accomplished in any one of several ways. The fruit may be dipped for 30-60 seconds into boiling water to which glycerine has been added at the rate of one pound to 20 or 25 gallons, or into a boiling brine solution made by dissolving 1 pound of common salt in 30 gallons of water, then allowing the fruit to lie upon a dripping board until the liquid has drained off before it is packed. The glycerine and brine treatments are sometimes combined by dissolving both salt and glycerine in the water. Some packers secure the same result by dipping the fruit in boiling hot prune-juice solution or in dilute sugar syrup, or by placing it in a steambox and subjecting it to live steam at 10-20 pounds pressure for a few minutes, although these methods are being generally displaced by the glycerine and brine treatment except in the larger, more completely equipped plants. The "processed" fruit is freed from adhering dust and dirt, and adhering eggs of insects are destroyed, the bloom and gloss characteristic of the fresh fruit is more or less perfectly restored, and the fruit packs more compactly into the boxes. Boxes of prunes are faced with a double layer of large perfect fruits selected for the purpose, these are laid in place by hand, pressed sufficiently to flatten them, and the box is then filled to proper weight and pressed as is the case with apples.

THE UTILIZATION OF EVAPORATOR WASTE

A ton of apples, when pared and cored, will yield approximately 600 pounds of parings, trimmings, and cores, called "waste" by the trade. This material has a sugar content

equalling or slightly exceeding that of an equal weight of the whole fruit, while its contents of pectin—that constituent of fruits which is responsible for the gelatinization or jellying of the boiled fruit-juice—is equal to that of whole fruit. Peels and cores are consequently valuable for any one of several purposes. In the Eastern evaporators, they are usually dried on the kilns in the same manner as the fresh fruit, and sold in the dry condition to vinegar and jelly factories, which exhaust the dried material with water. There is also an export trade in dried waste which is ultimately used for the same purposes. The laws of some states, including Washington, forbid the addition of water in the making of vinegar, hence dried peels and cores could not be used for the purpose where such laws are in force. They may be worked up for vinegar in the fresh condition by installing a press and generators and employing some one familiar with the process of vinegar making. Every ton of peels and cores will yield approximatèly 135 gallons of juice if pressed with a good hydraulic press, while the yield will be somewhat greater if small apples unfit for drying are pressed with them. The pomace after pressing has a feeding value for stock aproximately equal that of an average quality of corn silage[1], or it may be utilized in the manufacture of concentrated pectin for use in jelly-making[2].

The possibilities for the making of vinegar from pears and peaches have been investigated by Gore[3,4], who found that mature Kieffer pears yielded a juice too low in sugar to make a standard vinegar, while such peaches as Elberta, Belle of Georgia, Carman, Mountain Rose and Waddell yielded a vinegar of legal acid requirement. No studies of the possibilities of making vinegar from parings of these fruits have been made, but it is scarcely probable that an acceptable vinegar could be made from them, although the parings and cores of

1. Lindsey, J. B.—The Feeding Value of Apple Pomace. Mass. Agric. Expt. Sta. Circular 58. 1915.
2. Caldwell, J. S.—A New Method for the Preparation of Pectin. Wash. Agric. Expt. Sta. Bulletin 147. 15 pp. 1917.
3. Gore, H. C.—The Preparation of Vinegar from Kieffer Pears. Journ. Am. Chem. Soc. 29:759-764. 1907.
4. Gore, H. C.—The Value of Peaches as Vinegar Stock. U. S. Dept. Agric. Bur. Chemistry. Circular 51. 1910.

Bartlett pears, with their rather high sugar content, offer possibilities which might repay investigation.

Studies of the oils of peach, apricot, cherry, and prune kernels by Rabak[1,2,3] have shown that the kernels of all these fruits contain two oils which are chemically and physically closely similar if not actually identical with the oils of almond. Of these two oils, the fixed or non-volatile oil is widely used in the making of cosmetics, toilet preparations, emulsions, and as a vehicle in medicinal preparations, while the volatile or essential oil is employed medicinally. The supplies of these oils used in the United States were wholly made by German, French and English manufacturers and their importation has been greatly reduced within the past two years, in consequence of which the prices borne by both oils have materially increased. Since the work of Rabak has shown that the oils of apricot, peach, and plum and prune kernels may be substituted for all purposes for which almond oils are now employed, there may be a possibility of developing the American manufacture of these oils from such kernels. This will necessitate the employment of considerable care in the handling of the pits after removal from the fruit, since the oils deteriorate rapidly when the pits are wetted or allowed to heat, and the equipment necessary for the preparation of the oils is so expensive that the work should be undertaken only in a single centrally located plant capable of handling the entire output of these pits from a large territory.

COST OF CONSTRUCTING BUILDINGS

To present a complete itemized bill of materials and a detailed estimate of cost for each of the buildings described in the preceeding pages would require more space than is available. Such estimates have been prepared in detail. and will

1. Rabak, Frank—Peach, Apricot, and Prune Kernels as By-products of the Fruit Industry of the United States. U. S. Dept. Agric. Bur. Plant Ind. Bull. 133. 34 pp. 1908.
2. Rabak, Frank—The Utilization of Waste Raisin Seeds. U. S. Dept. Agric. Bur. Plant Ind. Bull. 276. 36 pp. 1913.
3. Rabak, Frank—The Utilization of Cherry By-Products. U. S. Dept. Agric. Bull. 350. 24 pp. 1916.

be furnished upon application to the Director of the Experiment Station, Pullman. Such requests must be accompanied by information as to the approximate capacity of the plant desired and as to the sorts and amounts of fruit other than apples to be handled by the plant, as this information is necessary in order that the plans and estimates sent may be fitted to the needs of the particular case.

The condensed estimates below are designed to furnish the prospective builder a working basis for his calculations of cost of his building. They supply accurate information as to the amounts and kinds of material necessary for constructing the buildings described, but costs of materials and labor vary considerably in the diferent districts, and are also increasing rapidly at the present time. Consequently actual cost of material must be substituted for the figures here given, which are quotations by Spokane contractors and hardware firms on June 1, 1917.

Materials and Cost of Construction for Two Kiln Plant.

If this plant be built of concrete, with concrete walls 8 inches thick, with concrete foundations 1½ feet wide and 1 foot thick below the ground level, it will require 80 cubic yards of concrete, which contractors in Spokane will put into the walls, furnishing everything necessary except reinforcing steel, for $8.00 per cubic yard, or $640.00; 1200 pounds iron rods at 6 cents for reinforcing concrete will cost $72.00, making a total of $712.00 for the concrete building. If brick walls 8 inches thick resting on a concrete foundation 1½ feet wide and 1 foot thick be used, they will require 53,500 brick, which contractors in Spokane will furnish and build into wall at $16.00 per thousand, or $756.00, with an additional charge of $86.70 for 288 cubic feet of concrete foundation, or a total of $842.70.

Other items of cost, which will be identical for the two buildings, are as follows:

Roofing, 3-ply asphalt, 1672 sq. ft. at $2.50 per square.....	$ 42.50
Or corrugated iron roofing, 1748 sq. ft. at $4.00 per square	72.00
Sills and joists, 618 feet of 6x6 ins. at $20.00 per thousand.	12.40
Rafters, 780 feet of 2x6 ins. at $20.00 per thousand.......	15.60
Framing for ventilators and bins, 450 feet of 2x4 ins. at $20.00 per thousand	9.00

Flooring, 1100 feet at $28.00 per thousand	30.80
Ship lap, for sheathing roof, 1800 feet; for bins, 1100 feet; for ventilator, 900 feet; for stairway, 400 feet; total 4200 feet at $16.00 per thousand	67.20
Chimney, concrete base and brick flue, complete..........	30.00
Concrete jackets and metal lath and cement hoppers around furnaces, two, complete	60.00
Furnaces, brick, with firebrick lining, 8x4x3½ feet, complete	54.00
Piping, 360 feet 9-inch pipe at 10 cents	36.00
Windows, 17 at $1.60 each...........................	27.20
Doors, steel, 8 at $4.00 each.........................	32.00
Framing and casing for doors and windows...............	37.50
I beams for supporting kiln floors, 80 feet, 1800 pounds at 7½ cents	135.00
Maple kiln slats, 720 square feet at $5.75 per hundred.....	41.40
Nails, hinges and minor hardware	25.00
Carpenters' labor, master carpented at $5.50; ordinary carpenter at $4.50 per day; 18 days each	180.00
Metal parts for bleacher, belts for conveyors, shafting, and belting from engine to main shaft..................	175.00
Lumber for paring table, conveyors, bleacher and chutes from storage bins, 1400 feet at $28.00 per thousand........	39.20

These items total $989.90 for building with asphalt roof and $1018.40 for building with corrugated iron roof. Adding these items to the cost of concrete or brick walls, we have $1701.90 for concrete building with asphalt roof, $1732.50 for same building with metal roof, $1832.60 for brick building with asphalt roof and $1863.10 for same with metal roof.

Materials and Cost of Construction for Four Kiln Plant. For a concrete building, with foundations 1½x1 feet under all walls, walls 8 inches thick, there will be required 155¾ cubic yards of concrete at $8.00 per cubic yard will cost $1246.00, with an additional cost of $150.00 for 2500 pounds of iron rod for reinforcement. If built of brick, 103,500 brick costing $16.00 per thousand laid in wall will cost $1656.00 with an additional cost for concrete foundation 1½x1 feet under all walls, 564 cubic feet at $8.00 per cubic yard, of $175.00, or a total of $1831.00.

Others items identical for the two buildings are as follows:

Roofing, 3-ply asphalt, 4264 sq. ft. at $2.50 per square.....	$107.50
or corrugated iron, 4583 sq. ft. at $4.00 per square....	184.00
Sills and joists, 2100 feet of 6x6 ins. at $20.00 per thousand	42.00
Fafters, 2000 feet of 2x6 ins. at $20.00 per thousand......	40.00
Framing for ventilators and bins, 1800 feet of 2x4 ins. at $20.00 per thousand..........................	36.00

Flooring, 3600 feet at $28.00 per thousand..............	100.80
Ship lap, for sheathing roof, 4600 feet; for bins, 1800 feet; for ventilator, 1800 feet; total 8200 feet at $16.00 per thousand	131.20
Chimneys, concrete base and brick flues, complete........	60.00
Concrete jackets with metal lath and plaster hoppers around furnaces, four, complete	120.00
Furnaces, brick with firebrick lining, four, complete.......	108.00
Piping, 720 feet 9 inch pipe at 10 cents.................	72.00
Windows, 32 at $1.60 each	51.20
Doors, steel, 17 at $4.00 each.........................	68.00
Framing and casing for doors and windows..............	77.50
I beams for suporting kiln floors, 160 feet, 3600 pounds at 7½ cents	270.00
Maple kiln slats, 2000 square feet at $5.75 per hundred feet	115.00
Minor hardware, nails, hinges, etc.	60.00
Carpenters' labor, master carpenter at $5.50; two ordinary carpenters at $4.50 each, 24 days each..............	348.00
Metal parts for bleacher, belts for conveyors, shafting, belt from engine to main shaft, belting to parers, etc......	250.00
Lumber for paring table, conveyors, bleacher, washing tank, and chutes from storage bins to paring tables, 3000 feet at $28.00	84.00

These items total $2141.20 for building with asphalt roof, $2220.70 for that with metal roof. When added to the cost of concrete walls, the total is $3537.20 for concrete building with asphalt roof, $3616.70 for concrete building with metal roof, $3972.20 for brick with asphalt roof and $4051.70 for brick with metal roof.

These estimates come very close to actual cost of construction in Spokane at the present time, but substitution of actual current prices of materials and labor for those quoted must of course be made in estimates made at any other time or place.

Materials and Costs of Construction of Tunnel Evaporator. The tunnel evaporator described on pages 55 to 69 and figured in the plans shown in Figs. XVII to XXI, requires a building 58x41 feet in width and length, 18 feet in height to eaves at higher side, and 14 feet to eaves at the lower side. For such a building, constructed of concrete, with walls 8 inches thick, and with concrete walls 6 inches thick dividing the furnace rooms to the second floor line, tunnels with metal floors and wooden walls and top, the cost of materials and construction, based on Spokane quotations June 1, 1917, would be approximately as estimated below:

Concrete work, 105 cubic yards at $8.00	$ 840.00
Iron rods for reinforcement, 2000 lbs. at 6 cents	120.00
Roofing, 3-ply asphalt, 3000 sq. ft. at $2.50 per square	75.00
Rafters, 1500 feet of 2x6 ins. at $20.00 per thousand	30.00
Sills and joists, 1600 ft. of 6x6 ins. at $20.00 per thousand	32.00
Framing for ventilators, bins, and tunnels, 4800 feet of 2x4 inch at $20.00 per thousand	96.00
Flooring, 5500 feet at $28.00 per thousand	154.00
Ship lap for sheathing roof, making bins, and ventilator, 8000 feet at $16.00 per thousand	128.00
Chimneys, concrete base and brick flues	60.00
Furnaces, three with firebrick lining, complete	60.00
Piping, 720 feet 9-inch at 10 cents	72.00
Runways for tunnels, 800 feet 1x⅞ inch, at $20.00	16.00
Metal sheets for floor of tunnels, 475 sq. ft. at $4.00 per square	20.00
Labor of constructing tunnels	150.00
20 doors for tunnels, at $4.00, 10 outer doors, at $4.00	120.00
22 windows, at $1.60 each	35.20
Lumber for paring and spreading tables, conveyors, chutes, and bleacher, 1200 feet at $28.00 per thousand	33.60
Labor in building conveyors, bleacher, chutes, and tables	135.00
Master carpenter at $5.50, ordinary carpenter at $4.50 per day. Carpenter's labor on floors, bins, ventilators, placing windows, etc.	320.00
Metal parts for conveyor, bleacher, shafting, belting	200.00
Minor hardware, nails, hinges, etc.	80.00
Trays, 1400 at 75 cents	1,050.00
Total	$3,828.80

It must be noted that this estimate is based upon prices of material at Spokane, Washington, June 1, 1917, and that more or less rapid increases in price of many kinds of building materials are occurring at the present time, also that current prices for a given material vary widely in different parts of the state, even to the extent of 25-30 per cent, at any given time. Hence the estimates of total costs here made are at best very general approximations, and intending builders should consider them as such and should investigate local prices of materials and labor before forming any conclusions as to the investment in a building required.

Costs of Construction of the Carson-Snyder Evaporator. By reason of the arrangement of the Carson-Snyder evaporator, a building of three stories and of an essentially different type from those described in this bulletin will be necessary, and the details of construction will vary considerably with the capacity which the plant is to have. For these reasons, no at-

tempt to give estimates of costs or of amounts of materials necessary for a building of a definite size is made; detailed plans and estimates suited to the requirements of each particular case will be supplied at actual cost to those making application to the Director of the Washington Agricultural Experiment Station at Pullman for them. In general it may be said that the cost of a Carson-Snyder evaporator of a given capacity will be almost identical with that of a tunnel evaporator of like capacity, if built of the same material.

COST OF PRODUCTION OF VARIOUS EVAPORATED PRODUCTS

The estimates of cost of production of various dried products here given are based upon actual cost data obtained from the books of a number of evaporating plants in Washington and Oregon, supplemented by a somewhat detailed study of the actual performance of various machines under commercial conditions and of the amount of labor actually required to produce a given output, made in western New York. It is believed that these estimates as nearly represent the actual costs of production as any figures, in the nature of the case, can do. At the same time it must be distinctly understood that they are estimates, and that there is no more definite answer to the question "What is the cost of producing a ton of dried apples?" than to the question "What is the cost of producing a bushel of wheat?;" indeed, both questions are identical in character in that the answers are obtained by considering a multitude of factors which are never identical in any two cases. Thus the cost of drying prunes, in plants of essentially the same capacity and general type and located in the same district, has been found to vary between $11 and $23 per dried ton, and similar wide variations, not always immediately explainable, are found when any number of cost sheets are compared. The figures here given assume that labor saving devices are employed wherever possible, that hand labor is reduced to a minimum and that the labor employed is in ordinary degree intelligent and dependable and that it can be retained

throughout the season, that the equipment is of modern type and kept in proper repair, that the plant is operated continuously through its working season, and that its management is in the hands of an efficient business man who can maintain pleasant relations with employees while securing good steady work.

Costs in the Kiln Drier.—Labor. In a kiln drier having a daily capacity of ten tons of fresh fruit, equivalent to 2500-2700 pounds of dry product, there will be required in drying apples six women or girls to operate paring machines, with eight trimmers, who are also women or girls. If the apples used are very small and there are many defects requiring trimming, there will be necessary an additional parer with two or possibly three trimmers, and if all the labor is inexperienced this larger number will be needed at the outset, but as an average through the season six parers with eight trimmers will keep the kilns supplied. There will also be required three men, working in shifts of 8 hours each, in charge of the furnace rooms and drying floors, and during the day shift, when the machines are running, two men will be required to assist in loading and unloading kilns, tending the bleacher and slicer, washing apples, and keeping machinery in good order. An additional man will be necessary in case fruit is being brought in from the orchards as it is used, to assist in unloading wagons, checking weights, and giving assistance wherever it is needed. Of the six men necessary, the three in charge of the drying floors and furnaces must be somewhat above the average laborer in intelligence and desire to learn, as the actual drying of the fruit will be in their charge, and that one having most experience in the work should be placed in charge of the "last shift," during which the fruit is finished and removed from the kilns. The other three men may be ordinary laborers.

With this working force the daily bill would be

14 women or girls at $2.00 each	$28.00
3 men at $4.00 each	12.00
3 men at $2.50 each	7.50
Total	$47.50

As the plant, when operated continuously, will produce 2500-2700 pounds of dried fruit in every twenty hours of working time, this labor cost may be charged against the last-named amount of product, which will give a labor cost of 1.83 cents per pound.

Fuel. With an efficient fire-brick furnace or a large hop stove, surrounded by a jacket and hopper, it should be possible to secure something like 65 to 75 per cent of the theoretical heating efficiency of the fuel used. In actual practice, one cord of fir, spruce or hemlock wood, or one and one-third cords of mill-slabs or cottonwood, will produce one ton of dried fruit. At $4.00 per cord for coniferous wood or $3.00 for slabs or cottonwood, this gives a fuel cost of .2 cents per pound.

Sulphur, Repairs and Minor Items of Expense. Repairs to machines and belting, oil for kiln floors, sulphur for bleaching, and similar minor items have been grouped together and estimated by a considerable number of experienced operators as averaging $1.40 per ton of dried fruit produced, while gasoline for power, or electric power at 2 cents per kilowatt, is estimated as averaging 80 cents per ton of dry fruit. Adding these items, they total .11 cent per dry pound.

Overhead Charges, Superintendence and Depreciation. Here it becomes impossible to make more than the most general statements, since the length of the working season, the character of the oversight of the business, and every element entering into the calculation is so highly variable. The plant may operate for only 60-80 days and with apples only, or it may double the working season and consequently cut overhead charges and depreciation in half by drying berries, peaches, apricots and other materials. In a considerable number of plants whose average working season was 70 to 90 days and in which the salary of the superintendent was charged against the plant only for the actual working season, the total cost of these items are upon the average slightly less than .5 cent per pound, and may be charged against the product at that figure.

Packing and Boxing. Boxes and labor of packing will cost, when fruit is packed in standard 50-pound boxes, about .5 cent

per dry pound. Combining these various items of cost of production, we have

Labor cost, apples	1.83	cents
Fuel	.20	"
Sulphur, oil and power, and minor repairs	.11	"
Overhead charges, superintendence, depreciation of plant	.50	"
Boxing and packing	.50	"
Total, per dry pound	3.14	cents

With the wages stated as being paid for labor in this estimate, these figures may be taken as a liberal estimate of the cost of producing dried fruit of prime or better than prime quality, packed in 50-pound boxes ready for market. If use is made of peels and cores, either in the making of vinegar or as food for animals, the returns realized therefrom will somewhat reduce this figure. In a number of efficient, well-managed plants which the writer has visited, the total cost of producing dried fruit, with labor and fuel costs figured upon the rates here given, is kept below 2.7 cents per dry pound.

Berries. In handling berries of any kind upon the kiln, the labor cost is restricted to the operators in charge of kiln floors and furnaces and to one man who receives and weighs fruit, with a second as helper in loading and unloading the kilns. The floor will receive only about 4 tons at a charge, but two charges will be dried in each 24 hours, giving a daily output from four kilns of 2900 pounds of fruit, with a labor cost of $15.00 or slightly more than .5 cent per pound. Fuel will cost $3.00 (for ¾ cord) per ton of dry fruit. The items of sulphur, oil, and repairs to machines do not here come in, and general overhead charges, superintendence, depreciation, and boxing and packing will be practically identical with the charges made for apples. The total thus arrived at, 1.65 cents per dry pound, is believed to be a very accurate estimate of the average cost of drying loganberries, while it is probably slightly higher than the actual cost of drying raspberries or blackberries, which give somewhat higher yields of dry fruit.

Peaches and Apricots. Under favorable conditions of weather two charges of apricots or peaches, halved without

peeling, will be dried in each 24 hours. With four kilns, each charge will consist of about 3 tons of green fruit, giving a total output of dry fruit of 1400 pounds peaches or 2100 pounds of apricots. An experienced operator will halve and stone about 1½ tons of fruit per day, so that four women with five men will be necessary to run the plant, at a total labor cost of $23.00 per day, or 1.53 cents per dry pound for peaches or 1.10 cents for apricots. Other items of expens, sulphur, repairs, and overhead expenses, with boxing and packing, will bring the cost of fruit packed in 50-pound boxes, to 2.75 cents per pound for peaches or 2.4 cents per pound for apricots.

Vegetables. In the case of the root vegetables, such as potatoes, carrots, and parsnips or beets, the labor cost of drying on kilns approximates very closely that of apples. The roots must be pared and trimmed by hand, but the force required to keep the kiln operating with apples will also pare and trim roots as rapidly as they can be dried. The force required in caring for the fires and tending the kiln floors will be the same as for apples, and the amount of fresh material placed upon the kilns at a charge will equal or slightly exceed a charge of apples. The daily labor, fuel and depreciation charges will therefore be about those for apples, but the yield of dry material will be almost double in the case of potatoes, 25 to 40 per cent greater in the case of beets, parsnips, or carrots. Consequently, these vegetables can be dried at a total cost between 1½ and 1¾ cents per pound, and the writer has inspected the books of a number of Eastern evaporators in which the total costs, estimating fuel and labor charges at the rates here employed, were under these figures.

In the drying of onions, cabbage, pumpkins, beans or peas, and green corn, no figures upon which to base estimates which would be dependable are at hand. These materials must be prepared for drying by hand labor, which varies so tremendously in its efficiency that estimates based upon scant data would be valueless. Operators of plants in localities in which these materials are obtainable in quantity must determine whether they can handle these materials at a profit by experiment.

Costs in the Tunnel or Carson-Snyder Drier. In a plant having a daily capacity of ten tons of fresh apples, the costs of drying apples will be distributed as follows:

Six parers, eight trimmers—fourteen women at $2.00	$28.00
Three drier tenders and furnace men at $4.00	12.00
Two ordinary laborers as general helpers at $2.50	5.00
Five spreaders at $2.00	10.00
Total	$55.00

This amount is to be charged against 2500 to 2700 pounds of dry fruit, giving a cost of 2 to 2.2 cents per dry pound. Fuel, sulphur, superintendence, boxing and packing, and minor repairs wil average as in the kiln drier, but depreciation will be higher, since trays rapidly deteriorate and must be replaced every third season. All these items will average 1.5 cents per pound, making a total cost of 3.5 to 3.7 cents per pound for drying apples when it is assumed that the plant operates only with apples hence has the entire items of interest and depreciation assessed against that product. In reality this would rarely be the case, since prunes and berries would also be dried, hence would share in carrying the constant expense.

Berries. The actual total cost of drying loganberries, blackberries, and raspberries in a number of the larger tunnel evaporators of Washington and Oregon, as ascertained from the operators, ranges between 2 and 2.3 cents per pound in plants having eight to ten tons daily capacity. The largest single element in this cost is for spreading; berries must be handled carefully and in small containers, and the spreading is necessarily much slower than in the case of other materials except apricots and peaches. The other items entering into the cost of handling are not essentially different from the estimates already given for other fruits.

Peaches and Apricots. Since these fruits must be spread in a single layer upon the trays, stone cavity uppermost, the spreading is a large item in the total cost, estimated by some operators as two-fifths of the total. Total costs for these fruits will average 2.8 cents for peaches, 2.6 for apricots, per dry pound.

Prunes. The investigations of Brown and Bradford in Oregon have shown that the cost of drying prunes, for labor, fuel, and packing, average about 1 cent per dry pound exclusive of interest on investment, depreciation, and superintendence, which will add 1-6 to 1-3 cent per pound accordingly as the plant has a longer or shorter operating season. Probably 1.25 cents per dry pound is a fair estimate of the total costs in the average plant.

MARKETING THE EVAPORATED PRODUCT

The Northwestern states, by reason of their geographical position and their distance from any other important fruit-growing territory, can find a ready market for any amount of evaporated fruits which may be produced. Former difficulties in disposing of such products have been due primarily to the fact that the material was made in small lots in widely separated districts hence could not be shipped at favorable freight rates; these difficulties have alraedy been largely overcome through the increase in production of dried prunes and berries. Washington is especially favorably situated in that she is in position to command the markets of British Columbia and Alaska, both of which have long been large purchasers of evaporated fruits, while in the interior her nearest neighbors, Idaho and Montana, two years ago consumed some 1400 tons of dried fruits originating outside their own territory. Furthermore, Russia, long a large purchaser of American evaporated apples and prunes through the intermediation of Hamburg importing houses, is now seeking to establish direct trade connections with American manufacturers of these products, and the existence of more direct lines of transportation naturally lead her to seek such supplies as can be furnished by the Pacific states in that territory rather than upon the Atlantic coast. Hence trade conditions brought into existence by the European war are bringing about oportunities for entrance into the Russian markets with such supplies of dried fruits as the state of Washington can produce, and once such trade connections are established, their continuance depends only upon the maintenance of high standards of quality.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF BOTANY
Bacteriology

PREPARATION AND USE
OF
PURE CULTURES FOR LEGUME INOCULATION

By

C. A. MAGOON and B. F. DANA

BULLETIN No. 149
April, 1918

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PREPARATION AND USE
of
PURE CULTURES FOR LEGUME INOCULATION

By

C. A. MAGOON and B. F. DANA

INTRODUCTION

Soil inoculation has been practiced in limited areas for some years. The very great importance of this practice, however, as a factor in increasing the fertility of the soil, as well as insuring a better crop, is just coming to be realized by practical agriculturists and other students of the soil. Here in the Northwest the matter has been receiving more and more attention, and the Washington Agricultural Experiment Station, in its endeavor to serve in greatest measure the needs of the State, has sought to make available to all the benefits to be derived from this practice.

Inoculation of fields by means of soil taken from areas already inoculated, which are free from weeds and other pests, is not always practicable, and the use of commercial cultures, as well as of those formerly supplied from the U. S. Department of Agriculture, has not always proved successful. For this reason this Station, two years ago, undertook to supply farmers of the State with fresh viable cultures in order to insure maximum results. The appreciation with which this work has been received is evidenced by the fact that during the last year pure cultures of the *Pseudomonas radicicola* have been supplied for over 9300 acres of leguminous crops.

Although the use of pure cultures supplied from this Station had given excellent results in the field, we did not feel justified in assuming that we were necessarily following the best

methods in the preparation and handling of these cultures. Consequently, measures were undertaken to learn how the work was being done at other tations, in order that we might improve upon our own practices and give to others the benefits of our investigations. On the whole, our inquiries met with prompt and hearty response from those interested in the matter throughout the country. In a few instances we were not successful in getting the information sought, but the returns seemed sufficiently full to warrant a digest of the material, and the drawing of some conclusions.

LABORATORY EQUIPMENT REQUIRED

Where the usual bacteriological laboratory apparatus is available no extra equipment is found necessary, other than supplies of bottles or other containers in which the cultures are grown and shipped.

IN WHAT FORM SUPPLIED TO THE FARMERS

In general, cultures are supplied upon nitrogen-free solid media in tubes and bottles. In some instances, liquid media are used, and in others the cultures are supplied to the farmers in sterilized sand or soil. At least one Station makes a practice of furnishing soil from inoculated fields. In our practice, during the last two years, sterilized sand in tin soil cans has been used for this purpose, the organisms being cultivated in flasks, transferred to the sand by use of sterile water, and the can then sealed just previous to shipment. This method has proved satisfactory, so far as positive inoculation is concerned, but handling the sand in cans is cumbersome, and transportation charges are heavy. In addition, some complaints have been made that the sand causes excessive wear on seeding machinery.

COST OF CULTURES

The general practice among Experiment Stations and State Departments of Agriculture is to supply cultures to the farmer at cost. This cost varies, naturally, with the different methods of preparation and handling, but reports indicate that in any

case cultures can be supplied to farmers as a cost of from 25 cents to 40 cents per acre. Some Stations supply the cultures in limited amounts free of charge. Our own practice has been to charge a uniform price of 25 cents per acre, which we have found sufficient. Increase in the price of raw materials and of labor may necessitate a slight advance in price, but such is not anticipated.

STRAINS OF PSEUDOMONAS RADICICOLA USED

For the most part, is is believed that the same strain of *Ps. radicicola* infects the roots of alfalfa and sweet clover, and therefore the same culture may be employed for both.

A second strain is effective for the clovers belonging to the genus trifolium.

A third strain isolated from the vetch is applicable for the varieties of this legume. While some recommend the use of the vetch strain for garden peas, we have felt safer in the use of a strain isolated from field peas, for this legume.

Our tests have shown that the strain isolated from the field pea may be used successfully, not only for the field and garden varieties, but also for sweet peas.

In like manner, we have been successful in the use of a strain isolated from garden beans for all varieties of this legume.

Cow peas and soy beans are not planted to a large extent in this section, so we have had no occasion to investigate the strains of the organism necessary for the inoculation of these crops. From such information as we have, each seems to require its own particular strain.

It is common practice at the various Stations to supply strains of the organism freshly isolated from locally grown legumes for which crops they are later to be used. This, of course, is the safest and best practice.

APPLICATION OF CULTURE TO SEED

Considerable variation in methods employed in the application of cultures to seed has been noted. In some instances it is recommended that glue be added to the suspension of bac-

teria in order to cause them to adhere to the seed, while others advise specifically against this practice. The cultures themselves are more or less gelatinous in nature, and special measures to cause them to adhere to the seed do not appear necessary. We can see no advantage to be derived from the use of glue. On the other hand, since glue is usually heavily infested with bacteria of various kinds, antagonism of types may result in the destruction of the desirable nitrogen-fixing forms.

Sugar, and also milk, are sometimes used in the preparation of the suspensions for seed treatment, the object being to furnish nutrients for the bacteria. We have never investigated the desirability of this practice. Uniformly good results have been obtained without the use of materials of this sort, and they do not appear to us necessary. Furthermore, addition of these materials complicates the work of the farmer, and experience has shown us that this should be avoided whenever possible.

In the application of any culture to seed, care must be taken to thoroughly and evenly moisten the seed with the suspension of the bacteria. The seed of alfalfa and clover must be allowed to dry sufficiently to facilitate planting, but the drying should be done away from direct sunlight. With larger seeds, such as peas and beans, it is unnecessary to dry them, and the most convenient practice is to add the culture to the seed in the field as it is put into the drill. All treated seed should be planted as soon as possible. Handling of all cultures and of seed after treatment should be such that the bacteria will not be killed by exposure to direct rays of the sun.

REINOCULATION

Whether reinoculation is necessary the following year, or for several years after, is a question which is very frequently asked. It is impossible to answer this question in every case as it has been shown that in some regions limiting factors, probably drought and soil acidity, are operative, which cause the death of the organisms in the soil and make reinoculation necessary, even during the following season. In other regions one inoculation has been found sufficient for a period of years.

In the Palouse country we have found the soil heavily inoculated with the nodule-forming bacteria three years after their first introduction, although two non-leguminous crops had been introduced between the leguminous crops in the rotation.

This subject of the factors which limit the retention of these organisms in the soil is one which needs further careful investigation. Likewise, the question of whether or not these organisms when existing free in the soil may perform any desirable function is worthy of further study.

LABORATORY CULTIVATION

To the laboratory worker the methods employed in the cultivation of the bacteria and their preparation for shipment are of special interest. Because of the great surface which is afforded, flat bottles or "Blakes" are commonly used for this purpose. Test tubes are used to some extent, though bottles of 2, 4, and 8 ounce capacity appear best adapted for laboratory cultivation. We have used 8 ounce "Baltimore ovals" and also one-half-pint whiskey flasks for this purpose, with satisfaction, but any flat bottle which is fairly insoluble, and will stand sterilization, will serve. For all round laboratory use the "Baltimore oval" bottle (Whitall Tatum Co., Philadelphia, Chicago and San Francisco) is unsurpassed.

The medium is sterilized in the bottle, the bottle is then laid flat on the table or shelf to allow the medium to solidify, and when cold is ready for use. We have found inoculation most easily and satisfactorily effected by introducing 1 cubic centimeter of a suspension of the organism into the flask, with a sterile pipette, and then distributing the same over the surface of the medium by tilting back and forth.

Incubation is carried on at ordinary room temperature, as a rule, either in cupboards, or in rooms provided with shelves for the purpose. Such rooms should preferably be dark, but at least the light should be subdued.

The duration of incubation preceding the sealing for shipment varies with different workers. Some report 48 hours as sufficient, but from one to two weeks is more commonly

employed. We have rarely used cultures of less than one week's growth.

The amount of culture required per acre has not been standardized, though the growth of a solid medium in a flat 2-ounce bottle is usually considered sufficient for the inoculation of 2 acres. Two weeks' growth on the surface of the medium in an 8 ounce bottle is considered sufficient for from 10 to 15 acres.

How long cultures remain viable after being sealed is a very important question. Some workers consider that cultures are not reliable after 20 days from the time of sealing; others think one month not too long. Where sand is employed as the vehicle for distribution, longer periods are permissible than when cultures are supplied to the farmer upon the original culture medium. We have found the organisms alive in our sand preparations, and capable of forming nodules, as long as 8 months after the cans were sealed. One cubic centimeter of the liquid drawn from the sand showed as high as 3,000,000 bacteria at that time. However, we do not advise the use of such cultures, and have, in fact, advised against the use of cultures over three weeks old. Our investigations on the viability of cultures in sand have not been completed.

This is a very important consideration, as failure of cultures to produce good results in field practice has doubtless been due very largely to the fact that these cultures were too old, and the organisms were either dead, or their vitality greatly weakened. Cultures, then, should be obtained directly from a nearby laboratory, if possible, and in any case the purchaser should satisfy himself that all cultures used are fresh.

INVESTIGATION OF CULTURE MEDIA*

In our survey we found but slight uniformity in the composition of the culture media used by different workers. Being anxious to determine which of these was best adapted for

*We are greatly indebted to Mr. L. T. Ruehl for his valuable assistance in the laboratory studies connected with this part of the investigation.

general cultivation of the various strains required in our work, we undertook a comparative study of both liquid and solid media made according to the formulae used by different Station workers. Since it has been our sole purpose to compare the relative merits of the different culture media, no reference is here given to the particular Station using a given formula.

Liquid Media

The different liquid media investigated were:

No. 1

Tap water	1000.00 cc.
KH_2PO_4	1.00 gm.
$MgSO_4$	0.10 gm.
Saccharose	10.00 gm.
NaCl, $FeSO_4$, $MnSO_4$	traces

No. 2

Tap water	1000.00 cc.
KH_2PO_4	1.00 gm.
$MgSO_4$	0.10 gm.
Dextrose	20.00 gm.
NaCl, $FeSO_4$, $MnSO_4$	traces

No. 3

Tap water	1000.00 cc.
KH_2PO_4	1.00 gm.
$MgSO_4$	0.10 gm.
Mannit	20.00 gm.
NaCl	trace

No. 4

Tap water	1000.00 cc.
KOl	2.00 gm.
$MgSO_4$	1.00 gm.
NaCl	1.00 gm.
$CaSO_4$	1.00 gm.
$Ca_3(PO_4)_2$	1.00 gm.
Saccharose	10.00 gm.

No. 5

Tap water	1000.00 cc.
$(NH_4)_2HPO_4$	8.00 gm.
$MgSO_4$	0.50 gm.
Saccharose	8.00 gm.

No. 6

Nutrient broth (Standard)	1000.00 cc.
Saccharose	50.00 gm.

No. 7

Distilled water	1000.00 cc.
KH_2PO_4	1.00 gm.
$MgSO_4$	0.50 gm.
Saccharose	10.00 gm.

No. 8

Tap water	1000.00 cc.
KH_2PO_4	1.00 gm.
$MgSO_4$	0.05 gm.
Dextrose	10.00 gm.

No. 9		No. 10	
Tap water	1000.00 cc.	Tap water	1000.00 cc.
$Mg_3(PO_4)_2$	0.50 gm.	K_2HPO_4	1.00 gm.
Dextrose	10.00 gm.	Saccharose	12.00 gm.
		10% solution of $CaCl_2$, $FeCl_3$, $MgSO_4$, $MnSO_4$	3 drops

No. 11		No. 12	
Tap water	1000.00 cc.	Nutrient broth (Standard)	1000.00 cc.
KH_2PO_4	1.00 gm.	Dextrose	10.00 gm.
$MgSO_4$	0.20 gm.		
Saccharose	10.00 gm.		

Technique of the Test

Culture solutions prepared according to the above formulae were distributed in quantities of 65cc. into 8-ounce flasks, and sterilized. Inoculation of these was made from cultures one week old on a medium of the following composition:

Tap water	1000.00 cc.
K_2HPO_4	1.00 gm.
Saccharose	10.00 gm.
Agar agar	20.00 gm.

A suspension was made by washing the growth from the surface of the medium with a small quantity of sterile water, and 1 cubic centimeter of this suspension was introduced into each flask, with aseptic precautions. The flasks were then well shaken and placed in lockers at room temperature to incubate. Tests were made in triplicate on each of the five strains for which we have demand, namely, those isolated from alfalfa, beans, clover, peas, and vetch. After incubation for 10 days each culture was well shaken and one standard loopful was transferred to 1 cubic centimeter of sterile water previously placed in the sterile Petri dish. The plates were then paured with nitrogen-free agar of the composition given above.

After 4 days incubation at room temperature these plates were examined for colony growth.

Upon the basis of these tests the values of the media were found to stand in the following order:

Medium No. 5	1st	Medium No. 10	6th
" No. 6	2nd	" No. 11	7th
" No. 12	3rd	" No. 3	8th
" No. 2	4th	" No. 1	9th
" Nos. 4, 8, 9	5th	" No. 7	10th

Solid Media

The different solid media investigated were:

No. 1

Tap water	1000.00 cc.
KH_2PO_4	3.00 gm.
Saccharose	10.00 gm.
Maltose	10.00 gm.
Leachings from 15 gms. of hardwood ashes	
Agar agar	15.00 gm.

No. 2

Tap water	1000.00 cc.
KH_2PO_4	0.20 gm.
Mannit	15.00 gm.
$MgSO_4$	0.20 gm.
$CaSO_4$	0.10 gm.
$CaCO_3$	0.50 gm.
NaCl	0.20 gm.
Agar agar	15.00 gm.

No. 3

Tap water	1000.00 cc.
KH_2PO_4	1.00 gm.
$MgSO_4$	0.20 gm.
Maltose	10.00 gm.
Agar agar	10.00 gm.

No. 4

Distilled water	1000.00 cc.
KH_2PO_4	1.00 gm.
$MgSO_4$	0.20 gm.
Saccharose	10.00 gm.
Agar agar	10-15.00 gm.

No. 5

Tap water	1000.00 cc.
Saccharose	10-15.00 gm.
Leachings from 5 gms. of hardwood ashes	
Agar agar	10.00 gm.

No. 6

Tap water	1000.00 cc.
K_2HPO_4	1.00 gm.
Saccharose	10.00 gm.
Agar agar	20.00 gm.

No. 7		No. 8	
Tap water	1000.00 cc.	Tap water	1000.00 cc.
$(NH_4)_2HPO_4$	8.00 gm.	K_2HPO_4	0.20 gm.
$MgSO_4$	0.50 gm.	$MgSO_4$	0.20 gm.
Saccharose	8.00 gm.	$CaSO_4$	0.10 gm.
Agar agar	15.00 gm.	$CaCO_3$	5.00 gm.
		NaCl	0.20 gm.
		Saccharose	15.00 gm.
		Agar agar	12-15.00 gm.

A small quantity of $CaCO_3$ was also added to each flask.

The technique of the tests upon these media was essentially the same as that of the culture solutions,—the source of cultures, the temperature, periods of incubation, etc., being practically identical. In determining the amount of growth, however, the plates were prepared by first making a setrile water suspension of the growth in each flask, equal in volume to that of the liquid media, and then proceeding as in the case of the liquid cultures. In this way it was possible to compare directly the values of the solid and the liquid media.

Of the eight solid media tested, four (Nos. 2, 4, 6, and 8) were so far superior to the others that these latter were discarded. These four were so nearly equal in the amount of growth that a choice among them could not be made. Comparison of the plates from these with the plates from the liquid media showed the amount of growth present to be many times that obtained in the best of the liquid cultures.

In order to determine, if possible, which of these four media was best suited for use in the shipment of cultures they were subjected to further tests. All bottles were sealed with paraffin and placed in storage at room temperature. At the end of 10 days, one lot, consisting of cultures of each strain on each medium, was removed from storage and tested as before; 130 cubic centimeters of sterile water were used in making the suspensions instead of 65 cubic centimeters, as in the first test. The growth obtained upon these plates failed to show

any distinguishable differences in the value of the four solid media. However, nothwithstanding the fact that the cultures had been sealed for 10 days, even at this dilution the growth was fully the equivalent of that found on the plates of liquid medium No. 5 when that was at its best.

At the end of 20 days another lot similar to the above was taken from storage, and a like test performed. Again we found no distinguishable advantage of one medium over the others as shown in the amount of growth produced. There was a marked reduction in the numbers of viable organisms, however, the growth in this instance being approximately one-half as great as that obtained upon the plates made ten days before. It will be seen, then that these cultures after being sealed for 20 days contained as many viable organisms as the best of the liquid cultures having free access of air.

In view of the fact that liquid cultures are difficult to ship satisfactorily, and also are much inferior to the solid media in production of growth, we feel that any one of the four solid media considered above should be used in preference to any of the liquid media tested for the cultivation and shipment of cultures.

We have not made extended tests of media Nos. 2, 4, and 8, but we have used medium No. 6 in the cultivation of the *Pseudomonas radicicola* in our laboratories for the last two years, with excellent results. It is simple in formula, and easy to prepare.

CONCLUSION

In brief, the facts brought out by this survey may be summarized as follows:

1. Cultures may be furnished to farmers with but little addition to the ordinary bacteriological laboratory equipment.

2. Cultures supplied to the farmer at cost need not exceed the price of 40 cents per acre.

3. Strains of the *Pseudomonas radicicola* used are best obtained by direct isolation from locally grown legumes of the variety for which they later are to be used.

4. In applying cultures to the seed the use of glue or other adhesives is not necessary, and the use of nutrients in the preparation of the bacterial suspension is of questionable value.

5. Solid media are superior to liquid media for laboratory cultivation and shipment of pure cultures of the *Pseudomonas radicicola.*

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF BOTANY

Studies on the Morphology of Wheat

By

G. H. JENSEN

BULLETIN NO. 150
March, 1918

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Studies on Morphology of Wheat

By G. H. Jensen

INTRODUCTION

Being located in the midst of one of the most specialized wheat growing districts of the country, it is natural that much thought and activity concerning the practical improvement of this crop should obtain in the Washington State Agricultural College. Much investigational work has been done; more has been planned and is in progress. The work herein reported forms one essential part of a project designated to add something to our knowledge of the morphology and physiology of the developing wheat grain. Eckerson (39) has studied the microchemical changes that occur in the progressive development in the wheat plant, while Olson (40) has used the macrochemical methods in his studies on the gluten formation. The morphological development has also a fundamental relationship to the cereal investigations now in progress, especially those that are concerned with breeding and hybridization of wheats. Last, but by no means least, since the smut parasite is associated with embryonic tissue of wheat, the structural and physiological changes that occur in such tissue must be thoroughly understood as a basis for pathological investigations on this serious disease.

It seems in order to state here, that aside from making the necessary self-acquaintance with the morphological development as a basis for further physiological and pathological research on wheat, the writer has deemed it worth while not only to himself but possibly to other investigators to have the results which are now more or less ancient checked up in the light of more modern technique.

HISTORICAL

The morphologic work on the fruit of grasses began two hundred thirty years ago. Malphigi (1) in 1687 seems to have been the first to study the fruits of the great group

from a morphological point of view. He described the embryos of *Avena* and *Triticum*. One hundred years afterward Gaertner (2), working on a number of species gave the name scutellum; and Richard (3), twenty years later originated the name epiblast. The importance of these two structures from a taxonomic and morphologic point of view is evident from the fact that they have been in the foreground of research and discussion for a hundred years. An exhaustive historical resumé of the work dealing with the morphological structures of the fruits and grasses, together with an interpretation of the significance of these organs from a taxonomic standpoint was given in 1900 by Kennedy (34). Mirbel (4) in 1809 gave a definition of the fruit of the grasses as one in which, toward maturity, the ovary walls become united with the integuments of the seed. He proposed the name "cereum" for such a fruit. Since the promulgation of this very significant definition, researches on the developmental history of the Gramineæ have almost invariably taken into account the relation of integuments and nucellus to the envelopes of the mature seed. A comprehensive review of the literature, together with an important contribution to the phase of embryogeny of certain Gramineæ is given by True (26).

Since the year 1870 when Hanstein's (7) "Bahnbreckende Arbeit" appeared, contributions to the literature on various phases of the morphology of grasses have been added in an almost unbroken line. All those quoted below have been consulted in the preparation of this paper.

Anton Nowake (8) in 1817 was the first to present the developmental history of the wheat grain. His condensed account is, considering the technique at his disposal, remarkably good. Fleischer (9), in 1874 concerns himself chiefly with the more advanced stages of embryos. His thesis was to trace from their origin through various cell divisions, the development of organs such as plerome, periblem, dermatogen and root cap with reference to similarity and differences in dicots and monocots studied. Hagelmaier (10), in 1874 took up chiefly the older stages of embryos taking for his material half ripe and ripe seeds. Kudelka (11), in 1875 pre-

sented a detailed account of the structural development of the fruit of rye, from the time of blooming to the ripening of the seed, which is especially complete. Strausburger's (12) work in 1877 with 36 plates as well as his contribution (13) in 1879 with 22 double plates while neither take special note of wheat, are, nevertheless, of great value from a comparative standpoint. In 1879 Vesque (15) originated the name "Antipoden." Aside from that, his work is chiefly of comparative value since he was concerned with other grains. The work of Alfred Fischer (16) in 1880 deals with the development of the embryo sac in a large number of forms. His figures are the first to show a many celled antipodal tissue. Nörner's (18) work in 1881 on *Hordeum vulgare, Triticnm vulgare,* and *Secale cereale* deals entirely with older embryos much the same way that Fleischer (9) does with other groups of monocots and dicots. Two important contributions, Johannsen, W. (19), 1885 and Lermer and Holzner (21), 1888, dealing with the developmental history of barley were not available. The publications of Jumelle (22) in 1888, dealing with a discussion of the intiguments in grains were reviewed by True (26) in 1893; and Kennedy (34) in 1900 reviewed the work of Bruns (24), (1892). Golinski's (25), (1893) niaugural dissertation deals with the developmental history of the androeceum and gynoeceum of grasses. His conclusions will be further considered in the body of this report.

The most complete morphological and cytological work on wheat up to date is that presented by Koernicke (27) in 1896. His method of procedure, his technique and his conclusions leave but little to add to the developmental history of wheat.

The phenomenon of double fertilization had been brought prominently into the foreground in 1900. It is unnecessary to cite publications on that topic here, as the literature is amply reviewed by Coulter and Chamberlain (35) in 1903.

Cannon's (30) contribution (1900) is one of the most recent and will be used as a basis of comparison in a number of instances in this text. The most recent work bearing directly on this report are those of Brenchley and Hall (37) in 1909, Brenchley (36), (1909), and Brenchley (38), (1912).

Citations of their bearing on the author's results will be made in the body of the text.

METHOD

On the 22nd day of January, 1915, wheat was planted in 10-inch pots in the Experiment Station greenhouse of the State College of Washington. For the purpose of comparison three varieties, Bluestem, Marquis and Hybrid 143 were used. When plants were 5 to 8 cm. high considerable thinning out was done in order to insure more vigorous shoots and stools.

A similar planting was made on the 17th of February and a third one on the 20th of March. The purpose of this triple planting was, in part, to have on hand material of different stages of development for the morphological study, and also in part for the contemplated work by Dr. Eckerson (39), whose work is now published in bulletin 139 from this Station.

Nothing further was done than caring for the growing plants until about the 1st of April when dissections of the stems of the first plantings, then some 30 to 45 centimeters high, was begun with the purpose of discovering the early stages of the spike. Unsuccessful attempts were made on four or five successive days but on April 6th the young spike, at that time, 1 to 2 millimeters in length was found. As soon as the proper node was located no difficulty was experienced in dissecting out even considerably younger heads. By using the 25 mm lens and dissecting microscope, the young spikes in the second planting (Feb. 17) could be dissected out. It became evident that even in this material the spike had advanced considerably beyond the primordial stage. In consequence, the latest planting (March 20) was used, and here the primordia of the spike (See plate I. figs. 1 and 2.) were found. The plants of this series were less than three weeks old and ranged from 10 to 15 cm. in height.

In Bluestem the first beginnings of the spike are laid down a very short distance, approximately 1 cm., above the surface of the soil, while in Hybrid 143 the beginnings of the spike are actually from 1 to 1½ centimeters below ground.

Beginning April 6th, collections were made every two or three days, until the wheat was ready to head out. During

the heading out period collections were made more frequently, once or twice a day. During the period in which pollen was being shed, four daily collections were made.

It may be stated here that later in the summer collections were made at intervals of two hours from hand pollinated spikes for a period of 60 hours subsequent to pollination. The purpose here was to check up effects of greenhouse conditions, with field conditions, and to get a close series of the events that occur during this critical period. Furthermore, statements vary as to the length of time intervening between pollination and fertilization in *Triticum*, *Avena* and other grasses, hence there was a further reason for the collection of specific evidence. After the shedding of pollen had ceased on greenhouse plants, collections were resumed twice daily for a week, followed by collections at daily intervals for a week, and for the rest of the time until material was ripe at intervals of two days. The first and second plantings in the greenhouse ripened about the same time, June 15-18. Many kernels were thoroly ripe and dry on June 20th, when the last collection was taken.

All subsequent observations were made upon fall sown Little Club wheat, collected from Plot A 10 of Field VI. of the rotation and cultural experiments on the Experiment Station Farm.

It will thus be noted that four varieties—two spring wheats and two winter wheats were used. That one of these was grown out of doors under normal field conditions; that three were studied from slides made in exactly the same way from material of the same age; that this material was grown at the same time under exactly similar conditions in the greenhouse. In spite of this comparative study however, no important morphological differences were observed within the varities studied.

All tissues were killed and fixed in the field. that is, immediately after severing from the growing plant, in the ordinary 1% chromic-acetic acid, the killing and fixing period varying from twelve hours for the youngest material to sixty hours as the tissues grew older. Subsequently the usual methods of washing and dehydration were followed. Thoro

infiltration with chloroform, soft parafin and chloroform, and a relatively long infiltration in 54° parafin gave uniformly good results even with the mature grains. Sections were cut 5 to 8 microns thick and stained in Flemming's Safranin Gentian violet—Orange G, triple stain. All figures appearing in this article are camera lucida drawings according to magnifications specified.

DEVELOPMENT OF THE SPIKE AND FLOWER

The primordia of the spike are laid down early. Material gathered April 10, from wheat planted in greenhouse March 20, showed unmistakable evidences of it (See Plate I. figs. 1 and 2). At this stage it appears as a slight protuberance at the center of some 3 or 4 layers of leaves. As before stated, this stage of development occurs near the surface of the ground in Bluestem and Marquis or slightly below the surface in Hybrid 143. This difference in the position of the primodia seems significant. As pointed out by E. F. Gaines it may mean the difference between spring and winter wheat. In other words may be the limiting factor with respect to winter hardiness. Further work is now in progress to test. this assumption. The plant at this time has leaves measuring 10 to 15 centimeters in height above ground. Rapid elongation of the stem immediately below the spike now takes place simultaneously with the development of the spike. When the spike has reached a total length of 2 mm. (See Plate I. fig. 9.) the wheat plant is 30-45 centimeters high and the spike has been elevated to 20-25 cm. above the surface.

It will be seen by reference to Plate I. figs. 1-8 that very early there appears upon the young spike small side protuberances, first one or two, then four, six, eight and so on, until the stage represented in figure 8 there are 18 or 20. These are the beginnings of the lateral spikelets or rachillæ. By referring to figs. 9 and 10 of the same plate it will be seen that aside from the elongation of the main axis the greatest changes are taking place in the spikelets. If we now turn our attention to the lower set of figures, (Plate I. figs. 11 to 24.) there is apparent a striking similarity in the earlier stages of

the spikelet to the appearances in the whole spike. At first slight protuberances only, then lateral outgrowths which by their unequal enlargements give rise to conical structures, (Plate I. figs. 22, 23 and 24). These in turn organize themselves into groups (Plate I. figs. 25, 26, 27 and 28.) each group representing a flower with the beginnings of its various organs. About two days before the time of pollination, a longitudinal section through the flower has the appearance shown in Plate I. figs. 29 and 30. It will be noticed in these figures that the outer glume is the largest member and that the stamen is slightly in advance of the pistil. Fig. 30 is a median longitudinal section at approximately the same stage of development as Fig 29. Fig. 30 is also a median longitudinal section through a flower slightly older. The cut, however, is in a plane at right angles to Fig. 30. From these two figures it is apparent that the ovule is bent over on its funicle; i. e., is anatropous, so that the micropylar end falls inward toward the stalk of the spike. Fig. 32 is a portion of a spike showing flowers of the same stage of development as figs. 29 and 30. The spikelets on the lower part of the head lag behind those on the middle part of the spike. This is also true of the upermost 3 to 5 spikelets.

DEVELOPMENT OF THE MICROSPORE AND MALE GAMETOPHYTE

The primary archesporial cells arise as a single row (Plate II. fig 1.) when the spike in Hybrid 143 is approximately 5 mm. long. The primary tapetal or primary parietal layer and the primary sporogenous layer result from a periclinal division of the cells of this single row of primary archesporial cells. The primary taeptal row divides once more by periclinal division so that two tapetal layers is the rule. The innermost of these layers becomes surcharged with rich protoplasm and functions as a nourishing layer for the sporogenous tissue as it develops. By a further division of the primary sporogenous cells we have two and then four rows of pollen mother cells (Plate II. figs. 2 and 3).

Plate II. fig. 4 shows the first division of the pollen mother cell, and appears to have eight chromosomes. This agrees with Koernicke (27).

The pollen sac from now on increases enormously in size, and large spaces occur between the dividing pollen mother cells (Plate II. fig. 5). The pollen mother cells themselves increase to about twice their original diameter, round up, and their walls thicken somewhat. Finally division into two and then four daughter cells results in the young microspores (Plate II. figs. 5 and 6). These in turn separate from one another, become greatly enlarged and round up meanwhile developing a heavy outer wall (Plate II. figs. 7, 8, 9 and 10).

While these changes in wall structure are going on, the development of the gametophyte is occuring. The original microspore mucleus divides into two, thus giving rise to the vegetative, or tube, nucleus and the generative nucleus (Plate II. figs. 10, 11 and 12). The tube nucleus becomes enlarged and in some cases fusiform, but no further division takes place in it. The generative nucleus divides once, giving rise to the two male nuclei. These are all free nuclear divisions, no walls being formed. All this takes place before dehiscence of the microsporganium.

An interesting observation in connection with internal activities of this thick walled spore is its method of getting nourishment. So far as the writer has been able to ascertain, nothing similar has been recorded. Very soon after the tetrad division of the pollen mother cell has been completed, the young microspores arrange themselves along the walls of the sporangial cavity. (See Plate II. figs. 7 and 8.) On the side contiguous to the wall, there soon appears a papillar projection which indents the walls of the tapetal cells. (See Plate II. fig. 8.) The walls of these tapetal cells become resorbed at the point of contact, and gradually the cell contents disappear. While this is going on in the tapetal tissue, the spore is increasing in size, in thickness of wall, and internal complexity. Since the volumes of spheres are to each other as the cubes of their diameters, the ratio of the volume of the microspore just formed to the volume of the mature spore is readily determined. This was found to be approximately 1 : 25. It is therefore evident that there has been a considerable accumulation of substance. The question arises,

How did this substance get into the spore? It is generally conceded that the embryonic tissues draw upon surrounding structures for their nourishment and growth. This assumption is usually based upon the appearance of the contiguous disorganized tissues, coupled with the fact that the embryonic structures are enlarging even tho no apparent path of movement is in evidence. In the pollen grain of wheat, there is not only the disorganization and disappearance of surrounding tissue, and the enlargement of the spore, but also a definite organ for the ingress of food material. This organ is a small pore in the otherwise thick spore wall where nothing but a delicate membrane (middle lamella) intervenes between the plasma on the inside and that on the outside of the spore. (See Plate II, figs. 12 and 14). It seems to the writer, therefore, that we have nowhere a stronger complex of morphological evidence indicating the existence of a definite area for absorbtion than is shown in the pollen grain of wheat.

In Plate II. fig. 13, pollen grains are now mature and ready to be shed, in fact, at another point in the section from which the figure was made, dehisence was in progress. The male cells enter the embryo sac thru the pollen tube in the condition in which we find them before the pollen is shed. Since the subsequent changes that take place in the male gametophyte are concerned with the development of the pollen tube it is now in order to present the sequence of events and the mechanism provided for this stage.

The macroscopic appearance of the stigma in wheat is that of a feathery or wooly tuft of very fine, white, branching hairs. Upon microscopic examination, it is found that these hairs terminate in elongated thin walled cells. (See branches in Plate II. fig 15). The walls of these cells are covered with sticky exudate. When the pollen grain lodges among these hairs, the tips of the branches immediately begin to bend around it. (See Plate II. fig. 15). Hence, the stigmatic hairs both by their adhesive properties and by actual coiling about them hold the pollen grains in place. By staining freshly dissected pistils in aqueous safranin and aqueous methylene blue, a good contrast is obtained, the pollen tube taking the safranin much more intensely than

the tissue thru which it is penetrating, while the pollen grain takes the blue. In this way it was noted that the pollen tube emerges thru the wall (always so far as noted by the writer, at the thin spot mentioned above). This method of extrusion of the pollen tube was also noted by Nowaki (8), who makes the following statement: "Auf der Narbe keimen die Pollenkerne in der Weise aus, das sich die Innerhaut durch eine runde, vorher mit einem Deckel verschlossene Offning der Auserhaut heraus stulpt und so ein Slauch ensteht, der alsbald and der Spitze fortwachst und den Kõrnigen Inhalt, Welcher aus der Pollenschlauch hinein wandert, weiter transportirt." Very soon after the extrusion of the pollen tube the delicate wall with which it came in contact is digested, an entrance is effected, and the tube makes its way down thru the terminal stigmatic cell, thence down thru the interior of the larger branches by a more or less tortuous passage (See Plate II. fig. 15.) until finally the ovary is reached and the male nuclei are carried down in the end of the pollen tube.

DEVELOPMENT OF THE MEGASPORE AND THE FEMALE GAMETOPHYTE

The primary archesporial cell arises from the second layer of cells at the tip end of the nucellus. (See Plate III. figs. 3 and 4). It may be recognized by its enlarged form, the richness of its cytoplasm and its large nucleus (Plate III. fig. 4). The first division of this cell gives rise to a primary tapetal and a primary sporogenous or megaspore mother cell, (Plate III. fig. 5). The megaspore mother cell then divides into two, (Plate III. fig. 6.) and each of these two in turn divides once more, giving rise to a row of four cells, each one of which is a potential megaspore. (Plate III. fig. 7). Only one of these megaspores functions in the formation of the embryosac. In the majority of cases noted by the writer it is the basal or inner one, which agrees with Strasburger (12), Koernicke (27), Cannon (30), and others, but it may be any one of the four. The other three cells soon disintegrate. This is the normal method of development not only among grasses but among other groups of

monocots and dicots as pointed out by Coulter and Chamberlain, (35).

In following the further development of the megaspore, we note first its rapid enlargement and encroachment on the other megaspore cells. As the enlargement goes on, the cytoplasm becomes vacuolate and the first division of the nucleus results in two free nuclei near the middle of the sac. (Plate II. fig. 8). Each of these nuclei in turn divides, resulting in four free nuclei, (Plate II. fig. 9) and by one more division there results eight free nuclei in the enlarged embryo sac. (Plate III. fig. 10). Three of these nuclei, the synergids and the egg, assume a position in the micropylar end of the sac. Three others, the antipodals, assume a position in the opposite end of the sac; while two remain in or near the center of the embryo sac and fuse after a time to form the primary endosperm nucleus. Rapid cell division immediately begins in the antipodals, resulting at the time of fertilization in a tissue of 36 or more cells. (Plate II. figs. 11, 12 and 13). This confirms the conclusion reached by Golinski (25), for *Secale cereale*, by Cannon (30), for *Avena fatua*, and Koernicke (27), for *Triticum vulgare*. In fact multiplication of antipodal cells is the usual thing among grasses. The same condition obtains among some of the grass allies, having been reported by Campbell (28, in Sparganiaceæ where he found upward of 150 antipodals, and Araceæ, where he reports 10 or more. Fusion of the polar nuclei was repeatedly noted. The fusion takes place as a rule immediately before the entrance of the male cell. On one occasion (Plate III. fig. 12) there was a fusion of the two polars and the male cell at the same instant. In the contiguous section (Plate III. fig. 11) is seen the fertilization of the egg. It is therefore evident that the triple fusion occurs very nearly synchronously with the fertilization of the egg.

FERTILIZATION AND EARLY EMBRYONIC DEVELOPMENT

From hand pollinated material in the greenhouse and also in the field, fertilization was observed at the earliest 32 hours and at the latest 40 hours after pollination. Hand

pollination at intervals of two hours during the whole day was equally efficient in showing fertilization from 32 to 40 hours afterward.

The micropylar end of the ovule bends downward and inward toward the rachis, the ovule being therefore anatropous. The micropylar end is overlaid with 3 to 5 layers of cells through which the pollen tube makes its entrance to the embryo sac. (Plate III. fig. 12).

At the extreme micropylar end lie the two large pear shaped or fusiform synergids. The egg lies just below and to one side of these. The pollen tube (at least in a number of observed instances) makes its way between the two synergids and discharges in the immediate vicinity of the egg. One male nucleus is thus very near the egg, with which fusion soon results the other travels down a little further and fuses with the definitive nucleus as in Plate IV. fig 1, or fuses with the two polars at the instant of their fusion. (Plate III. fig. 12).

The writer does not agree with the statement made and figured by Golinski (25), that the polar nuclei are at first in close contact with the egg apparatus, nor that before fertilization they pass down to the vicinity of the antipodals. The polar nuclei remain relatively stationary and their position is (in all preparations of the writer) nearly constant, i. e., nearer the egg than the antipodals but never very close to either. Fusion takes place at very nearly the same instant that the egg is fertilized. This does not agree with Koernicke's results, since he says, "Before fertilization the two polar nuclei have fused and formed the secondary embryo sac nucleus." He fails to say whether one of the male nuclei enters into this fusion. This ommission on his part is very significant in the light of Mendelian dominance of endosperm characters carried by the male cell in Fo. hybrids. The subsequent development of the endosperm, however, is much more rapid than the development of the embryo; for when the first spindle of the fertilized egg is observed there is a considerable number (8-16) of the free endosperm nuclei seen in the peripheral protoplasm (Plate IV. fig. 3) of the embryo sac. This rapid multiplication of free endosperm nuclei goes on until the embryo reaches the 4-8 celled stage and takes

place at the expense of the antipodal tissues as well as that of the nucellar tissue in the vicinity, the cells of both of which at this stage are practically devoid of nuclei and in a condition of rapid disorganization The ultimate fate of the antipodals, therefore, seems to agree with Cannon's (30) conclusion for *Avena fatua;* namely, that they are consumed by the endosperm in its development, rather than Koernicke's (27) idea that they serve nourishment for the young embryo.

When the embryo is 4-8 celled,. very little remains of the antipodal tissue. At this stage there is considerable massing of endosperm nuclei toward the micropylar end of the sac, and walls begin to make their appearance between these nuclei. The wall formation once started near the embryo, proceeds very rapidly along the now narrow and much elongated part of the embryo sac and thence into the larger body until practically the whole sac is filled with endosperm tissue. The protoplasmic contents of the cells near the embryo becomes very dense and the nuclei are large. They persist in this condition for a long time after the remainder of the endosperm has become poor in cytoplasm. There is always a zone of disorganized or partially disorganized cells immediately in advance of the developing embryo, indicating the digestion of these tissues and the absorbtion of food by the embryo. Later stages of the development of the embryo are well worked out by Brenchley (36), and Kudelka (11).

ENDOSPERM

As soon as fertilization has occured, the endosperm nucleus immediately enters upon a rapid division resulting in many free nuclei lying imbedded in the peripheral protoplasm of the embryo sac. In the center of this sac is a large vacuole. Encroachment upon this vacuole progresses by centripetal invasion of the protoplasm with its contained endosperm nuclei. The antipodal tissue, which attains its maximum development as a mass of 30 cells or more at the time of fertilization begins to be used up by the endosperm activities immediately after the triple fusion and in 8 to 10 days thereafter only fragments of cell walls and disorganized cell contents remain (Plate IV. fig. 5). Not only is the anti-

podal tissue contributory to the food of the endosperm, but the contents of the adjoining nucellar cells are evidently utilized, as is evidenced by their loss of nuclei and the paucity of their protoplasm. In the early stages of endosperm development the drain upon the antipodal tissue is especially noticeable, both by the richness of the plasma and nuclei of the endosperm in its immediate vicinity and by the rapid disorganization of the antipodals. Later on the food absorbtion by the endosperm involves all the nucellar tissue except its outer epidermis and the part immediately surrounding the embryo. These remnants of the nucellus are used for the deposit of coloring matter and constitute the pigment layer of the mature grain. This fact is of fundamental importance to students of plant breeding. In five or six days after fertilization there is a massing of the free endosperm nuclei toward the microphlar end of the sac. This may be caused by migration of nuclei in that direction or by the accelerated multiplication in that vicinity. In any event, it is evident that the concentration of activities is now transferred from the antipodal end to the micropylar end of the sac. By this time the embryo has attained the 4-8 celled stage. Cell wall formation in the endosperm near the embryo now begins. The progress of this wall formation is extremely rapid. In three days or less after cell wall formation in the endosperm started the whole embryo sac has been transformed from a large vacuole with its surrounding layer of free endosperm nuclei imbedded in protoplasm, to a compact tissue of cells, each with its cell wall, nucleus and cytoplasm. The alurone layer makes its first appearance as the outermost layer of the endosperm on the dorsal side (side opposite the furrow) of the grain in the form of small densly staining cells (Plate V. fig. 15). The first indication of this layer was not followed closely but is stated by Brenchley, (36), to be well marked in about a fortnight after pollination.

The aleurone cells become larger and generally cuboidal in shape, have large well marked nuclei, are rich in cytoplasm which in its turn lays down the well known amorphous aleurone grains of the wheat. At no time does this layer of cells contain starch. The changes in the carbohydrate content

of the wheat grain are discussed in another bulletin by Eckerson (39), hence only a very brief mention of it will be made here. Suffice it to say that starch makes its appearance in the pericarp or ovular tissue outside the endosperm, long before any vestage of it is present in the endosperm. It is visible in these tissues even before the wall formation in the endosperm is complete. That this starch is digested and transferred in soluble form to the endosperm seems evident from the fact that it disappears in the former tissue and makes its appearance in the latter. But the laying down of starch in the endosperm is a relatively late process. The later development of the embryo including the organization of the initial radicle and stem tissues is given by Branchley, (36). This author also discusses the formation and development of the various organs such as epiblast, scutellum, plumule, primary and secondary roots, and the vascular cylinder. Strasburger (20), has given a complete account of the structure of the ripe seed and Brenchley, (36), has given an account of the events that occur in the germination of the wheat grain. The later developmental history of the wheat embryo is complete, and in order to avoid needless repetition the reader is referred to the above citations.

As a final suggestion the writer commends the perusal of the contributions by Branchley and Hall (37), Eckerson (39), and Olson, (40). These authors have given us extremely valuable data on the physiological and chemical changes that take place in the developing wheat grain.

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EXPLANATION OF PLATES

PLATE I.

Development of the Spike and Flower. From 1 to 9 inclusive, development of spike from its origin to 2 milimeters in lėngth.

Fig. 10. Portion of spike about two weeks before flowering.

Fig. 32. Portion of spike just before flowering showing the relative position of the floral members.

Figs. 11 to 24, inclusive. Development of young spikelet.

Figs. 25, 26, 27 and 28. Older stages in the development of the spikelet showing the flower groups.

Figs. 29 and 30. Median longitudinal section through flower just about time of fertilization.

Fig. 31. Median longitudnal section of flower in a plane at right angles to Figs. 29 and 30, showing the anntropous ovule, and position of one stamen.

PLATE 1.

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EXPLANATION OF PLATES

PLATE II.

Development of microspore and male gametophyte.

Fig. 1. Single row of primary archesporial cells.

Fig. 2. Two rows of sporogenous cells.

Fig. 3. Division in sporogenous cells giving rise to four rows of pollen mother cells.

Fig. 4. Pollen mother cell in first division showing half the somatic number of chromosomes.

Fig. 5. Shows the much enlarged sporagium with divisions of pollen mother cells to form microspores.

Fig. 6. Separation of and rounding up of young microspores.

Fig. 7. Further rounding up of young microspores and beginnings of papillary structure which ultimately results in an annular thickened portion around a pore.

Fig. 8. Further development of spore and thickening of its wall.

Fig. 9. Further development similar to fig. 8.

Fig. 10. First division of original pollen nucleus.

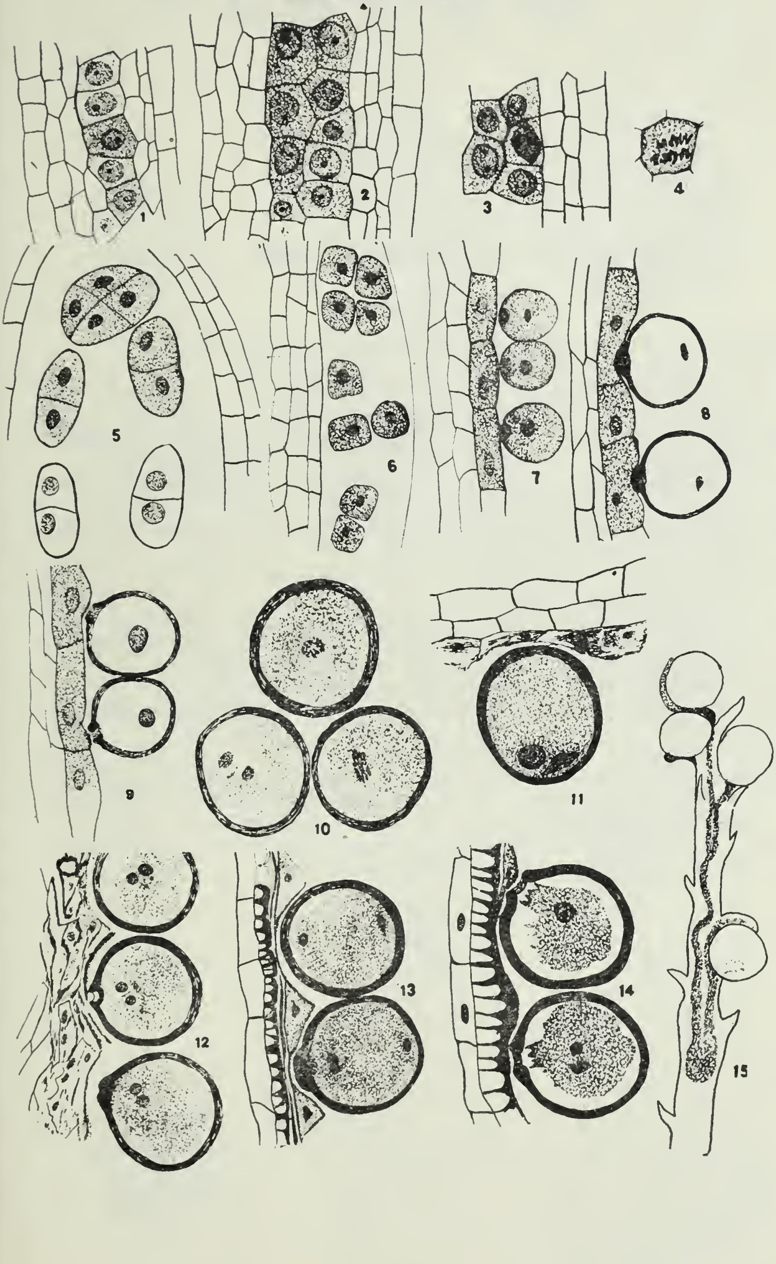
Fig. 11. Tube nucleus elongated; vegetative nucleus round, the resultant nuclei of divisions seen in fig. 10.

Fig. 12. Generative nucleus has divided forming the two male cells, but tube nucleus not seen. Disorganization of tapetal tissue.

Fig. 13. Mature pollen grain and dehiscence of sporangium. Male nuclei and tube nucleus. Tapetal tissue almost entirely resorbed.

Note: All figures in this plate were sketched under an Abbe camera lucida using a 1.9 mm. oil immersion objective.

PLATE 2



EXPLANATION OF PLATES

PLATE III.

Development of the megaspore and female gametophyte.

Fig. 1. Longitudnal section of young nucellar tip.

Fig. 2. Median logitudnal section of nucellar tip just before the formation of the primary archesporial cell.

Fig. 3. Tangential cut of nucellar tip showing the primary archesporial cell.

Fig. 4. Median longitudnal cut of nucellar tip showing the origin of the primary archesporial cell.

Fig. 5. Division of primary archesporial cell into the primary sporogenous and primary tapetal cells.

Fig. 6. First division of primary sporogenous cell showing also the large flattened tapetal cell.

Fig. 7. Second division of the sporogenous cells resulting in four potential megaspores. The lower one in this case apparenly destined to function in forming the embryo sac.

Fig. 8. First division of functioning megaspore nucleus.

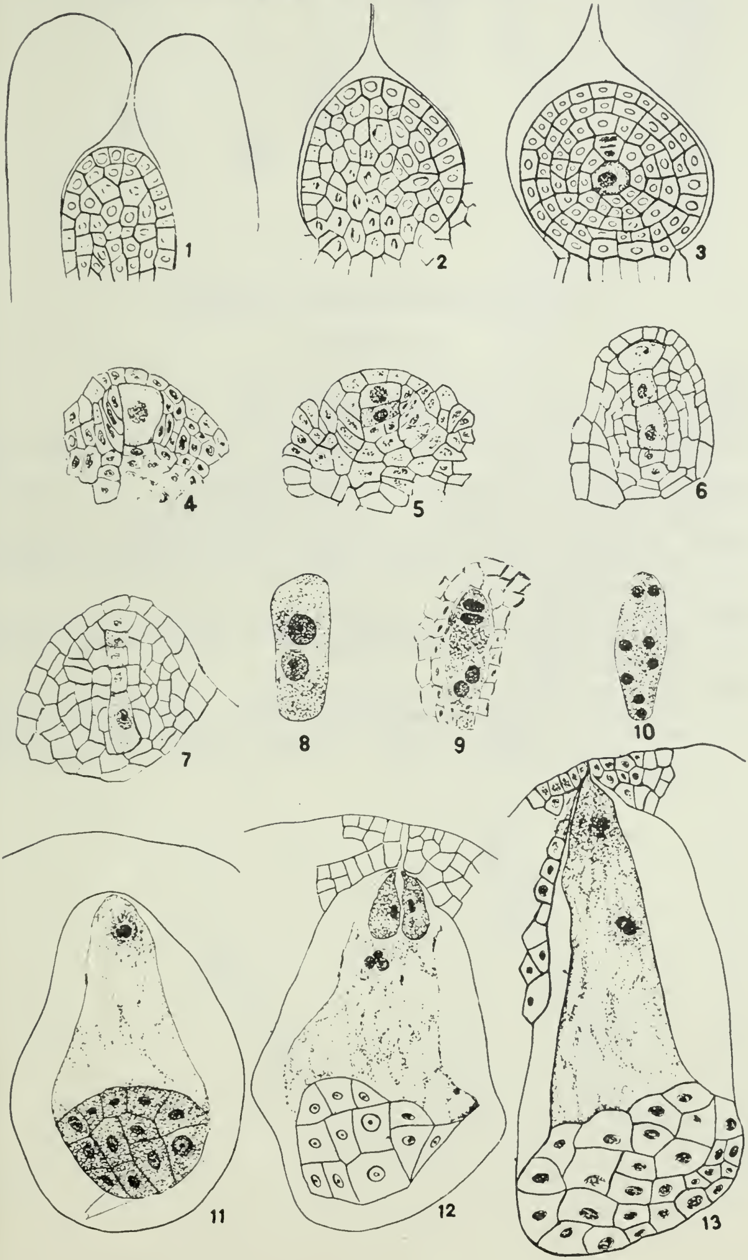
Fig. 9. Second division of megaspore nucleus—a four celled gametophyte.

Fig. 10. The eight celled gametophyte.

Figs. 11 and 12. Contiguous sections from same preparations. Fig. 11 showing fertilization of the egg; fig. 12 triple fusion of polars and male cell, also the two large fusiform synegrgids

Fig. 13. Fertilization of the egg and fusion of the two polar nuclei. Large development of antipodal tissue.

PLATE 3



EXPLANATION OF PLATES

PLATE IV.

Early stages in the development of the embryo.

Fig. 1. Fertilization of the endosperm nucleus.

Fig. 2. Second division of the endosperm nucleus—Fertilized egg in resting stage.

Fig. 3. Spindle of first division of the fertilized egg. About 16 free nuclei in the endosperm. Large antipodal tissue.

Fig. 4. Embryo two celled stage, slightly later than fig. 3. Numerous free endosperm nuclei. Enormous enlargement of vacuole of embryo sac.

Fig. 5. Four celled stage of embryo. Endosperm nuclei numerous and massing toward the microphylar end. Antopodal tissue nearly all disorganized.

Fig. 6. Embryo about the eight celled stage. Endosperm massed toward micropylar end and wall formation well advanced. Lower part of embryo sac still vacuolate in center with a sheet of protoplasm surrounding it and containing free endosperm nuclei.

PLATE 4.

EXPLANATION OF PLATES

PLATE V.

Later development of the Embryo.

Figs. 7, 8, 9 and 10. Gradual enlargement of embryo without any apparent differentiation of organs.

Figs. 10 and 11. Shows endosperm digestion immediately ahead of the advancing embryo.

Fig. 11. Embryo and endosperm about same stage as fig. 10. Outer cells on right (st) are starch containing. One layer (cl) contains plastids.

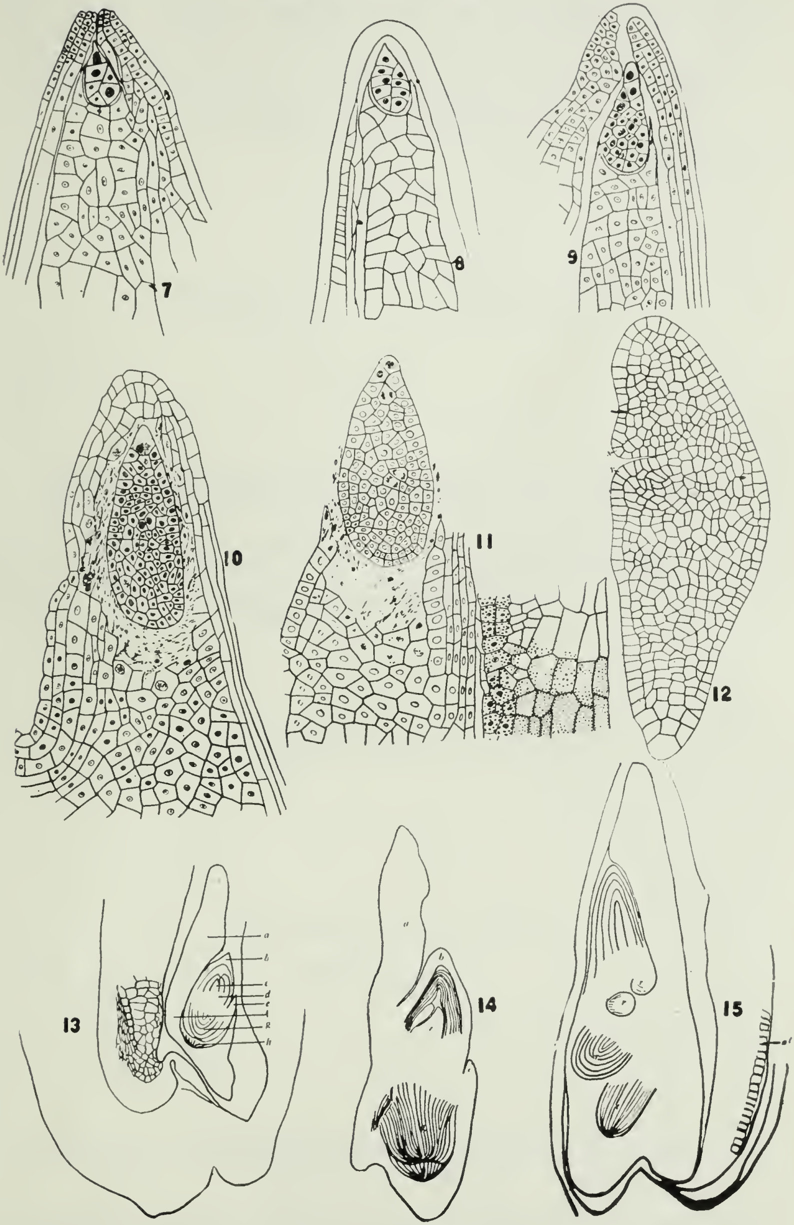
Fig. 12. Differentiation of embryonic tissue into organs. x, stem tip primordia; y, radical primordia.

Fig. 13. Diagram of lower part of grain of wheat showing embryo with radicle and root cap and also stem tip well organized. a, scutellum; b, sheath of cotyledon; c, growing apex of stem; d, hypocotyl; e, epiblast; f, coleorhiza; g, radicle; h, root cap.

Fig. 14. Diagram of embryo showing scutellum (a) and epiblast (e); stem tip (c) and root tip with root cap (h).

Fig. 15. Digram of older embryo showing stem tip and formation of four roots. Aleurone layer (al) shown on dorsal side. a, scuttellum; r, r, r, r, 1st, 2nd, 3rd and 4th roots.

PLATE 5



STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF PLANT PATHOLOGY

The Wind Dissemination of the Spores of Bunt or Stinking Smut of Wheat

By

F. D. HEALD and D. C. GEORGE

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THE WIND DISSEMINATION OF THE SPORES OF BUNT OR STINKING SMUT OF WHEAT

By F. D. Heald and D. C. George*

INTRODUCTION

During recent years the increased prevalence of stinking smut in the wheat fields of the Indand Empire has furnished one of the most important agricultural problems. This disease has been a growing menace to wheat production, notwithstanding the fact that seed disinfection has been very generally practiced. No satisfactory explanation had ever been offered for this rather unique condition previous to the investigations upon which this report is based. The recognition and establishment of the cause of the wide-spread occurrence of stinking smut is fundamental to the development of rational and effective methods of control.

The wide-spread occurrence of a fungous disease points to an effective dissemination, either natural or artificial. Fungous troubles may be seed-borne, or they may be disseminated by wind, water, insects, birds or other animals or by the commercial or agricultural practices of man. Since early times the stinking smut of wheat has been recognized as one of the most important seed-borne diseases, and seed treatment with fungicides has generally been effective in its control. The failure to secure the desired relief by seed treatment naturally suggests some other general method of dissemination aside from the use of infected seed. Work was begun on this phase of the smut problem in the summer of 1915 and has been continued up to the present time. Before presenting this work, a brief statement will be made concerning the general methods of dissemination of the smut fungi of cereals and the time when infection takes place.

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THE DISSEMINATION OF SMUT FUNGI OF CEREALS

The various smut fungi of cereals show a pronounced diversity in the methods of spore dissemination and in the time when infection takes place. Three general types may be recognized and a brief discussion of these will be presented in order that a clear view may be obtained of the particular species which forms the subject of this study. According to time of infection, the three groups are as follows:

1. Species producing a blossom infection.
2. Species infecting growing plants or those approaching maturity.
3. Species infecting only young seedlings.

In the first group the smut spores reach maturity in infected heads at a time when the flowers of the normal heads are in the blossom stage. The loose powdery mass of smut spores is dissipated by the wind, and the spores carried to the projecting feathery stigmas of the healthy plants. There is a direct germination of the spores with the infection of the young developing ovaries. This intraseminal infection causes no outward indication of the presence of an internal mycelium and the infected grains assume normal form and size. Such infected grains, when planted, may produce diseased progeny. The spread of the disease is due, first, to wind-borne spores during the blossoming period, and second, to the use of infected seed. This behavior is well illustrated by the loose smut of wheat (*Ustilago tritici*) and the naked smut of barley (*Ustilago nuda*.)

The second type is illustrated by the common smut of corn. Young plants or those approaching maturity are infected by wind-borne secondary spores or sporidia, which have resulted from the germination of the smut spores in the surface layers of the soil. The infections in this case are localized and not systemic, the mycelium penetrating the host only in the tissues adjacent to the tumors. Although spores of this species may be spread in other ways, the wind is the principal agent in the work of dissemination,

In the third type, which includes the larger number of our cereal smuts, the infection can take place only during the young or seedling stage of the host. The first essential for infection is the presence of smut spores in close proximity to the germinating seeds. These spores may be lodged upon the seeds and carried with them into the soil, or they may already be in the soil at the time of seeding. The source of the spores in the latter case must be either from a previous smutty crop on the ground (residual) or from adjacent or distant infected fields (wind-borne). Notable illustrations of this third type are loose smut of oats (*Ustilago avenae*) covered smut of barley (*Ustilago hordei*) and bunt or stinking smut of wheat (*Tilletia tritici* and *Tilletia foetans*). In the latter species all of the above sources of infection may occur, but our investigations have shown that wind-borne spores are very prevalent in Eastern Washington and adjacent territory. This is a phase of the dissemination of bunt which will receive special consideration in the following pages.

STUDIES OF STINKING SMUT IN WASHINGTON

A study of the work published by the Washington Experiment Station shows that first attention was given to seed treatment the same as in other wheat regions of the world. By 1911 the increased prevalence of smut in the Inland Empire due to fall seeding suggested the possibility of soil infection and the part of wind-disseminated spores in this increase was first suggested by Richardson in a thesis written in 1911 and further elaborated by Heald and Woolman in 1915 and 1916. The following publications by the Washington Station are given in chronological order and the brief summaries show the changing conditions and the development of our knowledge on the life history, prevalence, and control of bunt:

Piper, Chas. V.

1893. Common fungous diseases and methods of prevention. Bul. Wash. Agr. Exp. Sta. 8:131-144. 1894.
Description of stinking smut incorrectly referred to as *Tilletia foetans* Berk. & Curt.; recommends copper sulphate and hot water treatment, p. 135-136.

Beattie, R. Kent.

1902. The formalin treatment for wheat and oat smut. Bul. Wash. Agr. Exp. Sta. 54:1-8.
Considers loss, variation in susceptibility of varieties, description of smut, copper sulphate and hot water treatments.

Beattie, R. Kent.

1902. (?) The formalin treatment for wheat smut. Press Bulletin Wash. Agr. Exp. Sta. (unnumbered) 4 pages.
Considers nature of smut, losses, ineffectiveness of bluestone treatment, and recommends the formalin treatment.

Lawrence, W. H.

1907. Some important plant diseases of Washington. Bul. Wash. Agr. Exp. Sta. 83:1-56. 1907.
Stinking smut (*Tilletia tritici*) described and the formaldehyde treatment recommended, p. 43-45.

Humphrey, H. B.

?. The preventing of the stinking smut of wheat. Press Bulletin (unnumbered) Wash. Agr. Exp. Sta.

Anonymous.

1911. The anti-smut campaign. Press Bulletin Wash. Agr. Exp. Sta. No. 1.
Notes loss, increased prevalence due to fall seeding, possibility of soil infection and recommends copper sulphate or formaldehyde treatment.

Richardson, A. M.

1911. A comparative study of the methods of control of the stinking smut of wheat. Thesis (unpublished) on file in Library, State College of Washington.
Historical statement, life history of the fungus, partially smutted kernels, wind dissemination, treatments: hot water, copper sulphate and formaldehyde, are the prinicpal topics discussed. Ineffectiveness of the two methods generally employed, blue stone and formaldehyde, reported by practical farmers. Tests of formaldehyde or copper sulphate and the two combined.

Humphrey, H. B.

1912. The preventing of the stinking smut of wheat. Popular Bul. Wash. Agr. Exp. Sta. 48:1-3.
Considers copper sulphate and formalin treatment, and points to soil infection as explanation of certain cases of ineffective results; also records failure of fungicides to penetrate smut balls.

Anonymous.

1912. Treating seed wheat for smut. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 51.
Recommends either the formalin or bluestone seed treatment; emphasizes the importance of removing unbroken smut balls from the seed grain.

Woolman, H. M.

1914. Stinking smut of wheat. Popular Bul. Wash. Agr. Exp. Sta. 73, 8 pages.
Considers life history, breeding for resistant varieties, differences in susceptibility of varieties, time of application and strength of copper sulphate or formaldehyde in seed treatment, effect of threshing injury on germination of treated grain, persistence of spores in soil and effect of time of planting on the amount of smut.

Anonymous.

1914. Smut. Press Bulletin Wash. Agr. Exp. Sta. No. 113.
Refers only to Popular Buleltin 73.

Cardiff, I. D., et al.

1914. Report on fires occurring in threshing separators in East Washington during the summer of 1914. Bul. Wash. Agr. Exp. Sta. 117:1-22.
Demonstrates that smut dust is one of the causes of explosions in threshing separators and recommends methods of prevention and control.

Anonymous.

1915. Bunt or stinking smut of wheat. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 160.
A summary of results reported later in Bulletin 126.

Heald, F. D., and Woolman, H. M.

1915. Bunt or stinking smut of wheat. Bul. Wash. Agr. Exp. Sta. 126:1-24.
Considers life history of smut fungus, effect on the host, infection from smutty seed, infection from spores in the soil, residual or wind borne, control by crop rotation, clean seed, treatment with fungicides, cultural practices and breeding and selection of varieties.

Heald, F. D.

1916. Some new facts concerning wheat smut. Proc. Wash. State Grain Growers, Shippers and Millers Association, 1916:38-45.
Emphasizes the occurrence of partially smutted grains and gives further evidence of a general and extensive wind dissemination of the spores.

Woolman, H. M.

1916. The prevention of wheat smut. Proc. Wash. State Grain Browers, Shippers and Millers Association, 1916:45-49.
Emphasizes the importance of using clean seed and using one of the standard seed treatments; gives methods of combatting soil infection from previous crops or from wind-blown spores.

Anonymous.

1916. Smut. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 191. Emphasizes the soil infection by wind-blown spores and recommends either seeding before threshing time or late seeding or the abandonment of summer fallow wherever possible.

POSSIBILITIES OF WIND DISSEMINATION OF STINKING SMUT

The possibilities of a wind dissemination of bunt or stinking smut have been mentioned by a number of investigators. The first to be considered is the possibility of the production of wind-borne sporidia or secondary spores. This is not an unknown method of dissemination in cereal smuts, as may be noted from the following quotation from Brefeld:* "Some of these bud conidia are able to continue their budding in the air also and to form conidia there, which are disseminated through the air; as, for example, the bud conidia of the maise smut."

It has been observed that when spores of stinking smut are abundant in a soil, they may produce promycelia which come to the top of the moist soil and produce fascicles of sporidia in such profusion as to cause a grayish growth visible to the naked eye. This is apparently the condition which Brefeld had in mind when he mentioned the possibility of diffusible air conidia in bunt, or Tilletia species. If such conidia are borne away by wind or air currents, we have no evidence at present that they play a part in the general spread of stinking smut. Von Tubeuf,‡ who has experimented extensively with bunt in Europe, states that there is no spread of this disease from one plat to another and therefore concludes that there is no dissemination by aerial conidia.

There is little possibility of any wind dissemination of spores directly from the smutted heads as occurs in the case of loose

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*Brefeld, O. Investigations in the general field of mycology. Part XIII, p. 7. English translation by Frances Dorance.

‡Von Tubeuf, K. F. Arb. aus der Biol. Abteilung f. Land- u. Forstwirtschaft am Kaiserlichen Gesundheitsamt, 2:179-349. 1901.

smut. The smutted berries are wholly or partially concealed by the glumes and the smut mass covered by an enclosing membrane. Occasionally there may be a mechanical rupture of the enclosing mebmrane or the depredations of insects may result in the exposure of the smut spores, but there is no evidence that the agitation of these heads by the wind causes any appreciable liberation of the spores. Previous to harvest time there has been little or no opportunity for the dissemination of the smut spores. The first real opportunity offered for the setting free of the smut spores is in the threshing operations. It has long been a matter of general observation that many of the smut berries are broken in threshing and the spores dissipated. The extent to which this occurs depends on numerous factors, such as variety, maturity of crop at harvest, climatic conditions and speed of the threshing machine. The yield from very smutty fields sometimes shows a relatively small number of unbroken smut berries, the greater number having been broken. Part of the spores from the broken smut kernels adhere to the surfaces of sound grains, or are lodged in the sutures and brushes, but many must be carried out through the straw carrier, or stacker. The ultimate fate of the latter is of the utmost importance and indicates the possibility of wide-spread dissemination of these spores by the wind.

SUGGESTIVE EVIDENCE OF THE WIND DISSEMINATION OF SMUT

Various observations and experiences have given strong suggestive evidence of the wind dissemination of the spores of bunt. The following are the principal suggestive features that were brought to our attention and led up to the work which established the wide-spread prevalence of wind-disseminated spores.

1. The visible clouds of smut dust which issue from the threshing machines whenever the run is from a smutty field. Even with the use of ordinary separators, the innumerable number of settings must certainly set free into the air countless billions of spores, while the use of the combine serves as

an even more effective distributor. It must at once be evident that the spores in these visible clouds, being very minute, do not settle to the ground at once, and that their final place of deposit depends largely on the velocity of the wind. Any reflection on this matter would certainly lead to the conclusion that many of the smut spores set free from each threshing operation might be carried away for miles and thus scattered over the fields.

2. The presence of smut spores on vegetation distant from any threshing operation. This was first brought to our attention when making microscopic examinations of scab lesions on the leaves of apple trees from the College orchard. Wind dissemination of the spores was the evident explanation for their presence in such a location and this accidental discovery led to the systematic examination of foliage from various localities as will be discussed later.

3. Smutty wheat from clean seed on new land. This has been referred to in a previous publication* and will not be repeated in full. In some 1914 plantings on new soil using hand-threshed grain from smut-free heads, the percentages of smutted plants varied from a fraction of one per cent to sixty per cent. No other possible explanation for these results could be found except that the ground had been seeded with wind-blown spores.

4. The ineffectiveness of ordinary seed treatment for fall seeding. Two explanations for the failure to secure satisfactory results by seed disinfection had been given: first, the failure to remove the unbroken smut balls, either before or during the process of the treatment; second, soil infection due to a previous smutty crop on the same land. When, however, both of these possibilities were eliminated, carefully treated wheat frequently showed varying percentages of smut in the crop.

The apparent ineffectiveness of seed disinfection was the principal factor which led to the recommendation of the open

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*Heald, F. D., and Woolman, H. M. Bunt or stinking smut of wheat. Bul. Wash. Agr. Exp. Sta. 126:1-24. 1915.

tank method of seed treatment, rather than to any actual demonstration of the part which the unbroken smut balls played in these results.

Spring plantings have shown little or no smut when the seed has been carefully treated, but fall plantings on summer fallow have very frequently shown high percentages of smut. The following records taken from information collected by Dr. H. B. Humphrey and H. M. Woolman, were typical of the farm conditions in the vicinity of Pullman:

TABLE I.

Percentages of Smut on Winter Wheat with Careful Seed Treatment (Blustone)

Tract	Year	On Sum. Fal.	Variety	Percentage of Smut
146	1912	1911	Forty Fold	10-18 North Slope
144	1912	1911	Red Russian	20-25 North Slope
142	1912	1911	Club ?	30
136	1912	1911	Hybrid 108	21-24 South Slope
133	1912	1911	Hybrid 128	15-20 North Slope
129	1914	1913	Red Russian	15-20
131	1914	1913	Hybrid 143	22 North Slope

POSITIVE EVIDENCE OF WIND DISSEMINATION OF STINKING SMUT

Foliage Collections. The discovery of the spores of bunt on the leaves of apple (already mentioned) led to a more systematic search for these spores on the foliage of various plants. During the fall of 1915, leaf collections were made from various localities from the following: prairie sunflowers (Balsamorhiza), apple, maple, catalpa, box elder, spiraea, and snowberry (Symphoricarpos). Each lot (usually 25 leaves) was put at once into a clean paper sack and brought to the laboratory. With a clean test tube brush the surfaces of each leaf were scrubbed in a small amount of distilled water in a damp chamber. The operation of scrubbing was carried out in the laboratory inoculation chamber, thus allowing no spores to enter from the outside. To the washings was then added a sufficient amount of formalin to prevent the germination of the spores, and the entire amount placed in clean flasks or

bottles properly labeled and numbered. Counts determining the approximate number of spores present, were made at a later date.

The quantitative determination of the number of bunt spores found present on each lot was determined by the following method. The flasks containing the washings were thoroughly shaken in order to get into suspension all the spores present. With a 1 c.c. pipette a drop was removed to a clean slide and covered with a 22mm. slip, the edges of which had been smeared with vaseline to prevent the evaporation of the water during the count. By use of the mechanical stage the diameter of the microscopic field was definitely determined. In counting, the slide was placed on the stage and, beginning at the upper right hand corner of the slip, the slide was moved across the field of view the exact width of the slip. The number of spores found present was then recorded and the slide moved up the diameter of the field, when another count was made. This was continued until the entire area of the slip had been gone over and all the spores present in the drop had been recorded. The sum was then multiplied by the number of drops found necessary to make a single cubic centimeter, the product being the total number of spores present in a cubic centimeter. Ten drops were counted from each collection, the number of spores per cubic centimeter determined, and the average number per cubic centimeter multiplied by the total number of cubic centimeters in the flask, gave the number of spores to each collection (approximately). The results obtained are presented in the appended table. (Table II.)

TABLE II.

Showing the Number of Smut Spores Obtained From the Foliage of Various Plants During the Early Part of September, 1915

Collection No.	Date of collection, Sept.	Location	Plant	No. of leaves	Total No. of spores	Ave. No. of spores per leaf
1	9	College Orchard	Apple	25	1,865,266	74,610
9	9	College Orchard	Apple	25	3,631,792	145,272
3	10	Round Top	Maple	28	249,612	8,914
4	10	Round Top	Catalpa	15	693,594	24,669
5	11	Timber Claim S.W.	Box Elder	25	616,519	24,660
6	11	Timber Claim E.	Box Elder	25	760,557	30,422
7	11	Timber Claim C.	Box Elder	25	609,193	24,367
8	18	Kamiak Butte	Spiraea	30	266,475	8,882
9	18	Kamiak Butte	Balsamorhiza	6	28,353	4,725
10	18	Kamiak Butte	Symphoricarpos	22	31,317	1,423

When making the foliage collections, plants were selected which were located some distance from any wheat field or threshing operation. The leaves were taken from the various parts of the tree or plant, and no especial attempt was made to secure leaves showing a dense collection of dust.

Collections No. 1 and 2 were taken from two different trees, both situated in the northeast corner of the old orchard on the College farm. Collection No. 1 was from a large well-matured tree, with rather small leaves. No. 2 was from an adjacent tree which was younger, growing quite vigorously, and the leaves were somewhat larger. Both trees were on a southeast slope and situated in such a manner as to be quite well protected from the full force of the prevailing westerly winds. It is probable that bunt spores and dust would tend to settle at this particular point, which probably accounts for the large number of spores found on these collections. The nearest wheat field was at least a half-mile distant, and the nearest threshing operation much farther.

Collections No. 3 and 4 were taken from several trees located on the highest point of the College farm. These trees are not protected in any manner and receive the full force of the wind. The nearest wheat field was several hundred yards to the north and it is extremely doubtful if any bunt spores from this field ever settled on the foliage of these trees. The nearest wheat fields, west of this point, were two and one-half or three miles distant.

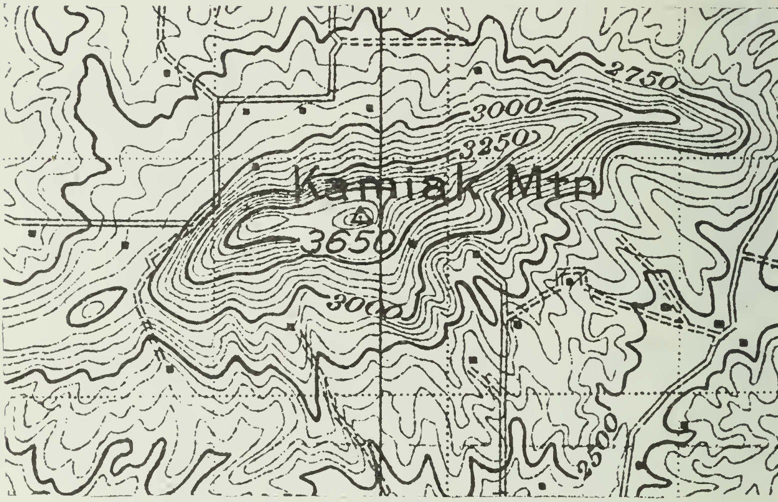

Fig. 1. Contour map of Kamiak and vicinity, photographed from the Pullman Quadrangle map of the U. S. Geological Survey, showing where foliage collections were made.

Collections Nos. 5, 6, and 7 were taken from a timber claim north of the College farm. This claim was located at the top of a hill and was surrounded on the north, west, and south sides by summer-fallow, while the east side only adjoined a wheat field. As the prevailing winds are mostly from the westerly directions it would indicate that if bunt spores could be obtained from the foliage within this claim, the summer fallow adjoining must be "seeded" equally as heavily. The foliage collections taken from the southwest corner, the center,

and the east side of the claim gave evidence of enough spores present, to warrant this conclusion.

Collections Nos. 8, 9, and 10 were secured from the highest ridge of Kamiak Butte at a point at least 1000 feet above the surrounding farms and two or more miles distant from the nearest wheat fields.

Water Spore Traps. The fact that the foliage of plants harbored bunt spores in large numbers at once raised the question as to the probable number of spores falling on a square inch of surface throughout the season. In order to determine this the use of the water spore-traps at once suggested itself. A description of these traps and their method of use is given in detail by Heald* et al., in their work on the air and wind dissemination of ascospores of the chestnut blight fungus.

Traps for 1915. Beginning September 1st and extending over a period of six weeks, ending October 14th, two spore-traps were stationed on the college farm at points distant from any wheat fields. Trap No. 1 was located at least one-fourth mile from the nearest wheat field and about one and one-half miles from the nearest threshing operation. Trap No. 2 was located on a point just south of Round Top (previously referred to), was equally as far distant from any wheat field or threshing operation, and with regard to elevation, was at least 150 feet higher than Trap No. 1. Collections were made weekly and all ordinary precautions were used to prevent the entrance of spores from other sources. The method of determining the approximate number of spores present in each collection was the same as that described for the foliage collections. The results are presented in the appended table. (Table III.)

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*Heald, F. D., Gardner, M. W., and Studhalter, R. A. Air and wind dissemination of the ascospores of the chestnut-blight fungus. Journ. Agr. Res. 3:493-526. 1915.

TABLE III.

Record for Spore Traps During Season of 1915, Showing Wind Dissemination of the Spores of Bunt

Period Covered	Trap No. 1			Trap No. 2		
	Total No. of spores....	No. of spores per sq. in...	No. of spores per sq. ft...	Total No. of spores....	No. of spores per sq. in...	No. of spores per sq. ft...
Sept. 1-Sept. 8......	155,175	3,978	572,832	119,262	3,058	440,352
Sept. 8-Sept. 16.....	58,806	1,507	217,008	63,591	1,630	234,720
Sept. 16-Sept. 23....	21,720	557	80,208	25,977	666	95,904
Sept. 23-Sept. 30....	17,028	436	62,784	12,995	333	47,952
Sept. 30-Oct. 7.......	4,926	126	18,144	2,475	63	9,072
Oct. 7-Oct. 14.......	12,078	309	44,496	8,712	223	32,112
*Total number of spores	269,733			233,012		
Total number per sq. in..	6,916			5,974		
Total number per sq. ft..	995,904			860,256		

*The area of the traps was found to be 39 sq. in.

Traps for 1916. With the approach of the harvest of 1916, it was decided to place the water spore-traps out earlier in the season and if possible, run them later. On August 16, three traps were stationed on the College farm, and weekly collections made for a period of eleven weeks, ending November 1st, when the temperature conditions no longer warranted their continuance. Traps. Nos. 1 and 2 occupied the same positions as during the year 1915, while trap No. 3 was stationed on the College Pathologium in a rather sheltered position. Trap No. 1 was equally as far distant from any wheat field or threshing operation as during the season of 1915, while trap No. 2 was but a quarter of a mile north of a very smutty field of wheat. Trap No. 3 was located in a summer fallow field, which for a number of years had been an old raspberry patch. To the south of the trap, but a few yards distant, was located some of the experimental plots used in growing spring wheat. All traps were set when harvest was at its height and about two weeks before any threshing operations began in the immediate vicinity. However, threshing and combine harvesting were at their height in the central part of the state, north and west of the College farm. It was our object to ascertain, if possible, the probability of wind dissemination from points 50 to 75 miles distant, the period of maximum dissemination in the immediate vicinity and the probable duration of the period of dissemination. Our results are recorded in the appended table. (Table IV.)

TABLE IV.
Record for Spore Traps During the Season of 1916

Trap No. 1

Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	62,483	1,602	230,688
Aug. 22-28	143,866	3,688	531,072
Aug. 29-Sept. 4	200,000*	5,128	738,432
Sept. 5-11	420,732	10,788	1,553,472
Sept. 12-18	212,512	5,449	784,656
Sept. 19-25	52,896	1,356	195,264
Sept. 26-Oct. 2	40,194	1,030	148,320
Oct. 3-9	15,225	390	56,160
Oct. 10-16	12,931	330	47,520
Oct. 17-23	6,467	165	23,760
Oct. 24-30	11,866	304	43,776
Totals	1,179,172	30,235	4,353,840

*Estimated.

Trap No. 2

Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	43,343	1,111	159,984
Aug. 22-28	155,261	3,978	572,832
Aug. 29-Sept. 4	146,421	3,754	540,576
Sept. 5-11	520,142	13,362	1,924,128
Sept. 12-18	250,000*	6,410	923,040
Sept. 19-25	164,867	4,227	608,688
Sept. 26-Oct. 2	21,309	546	78,624
Oct. 3-9	19,348	496	71,424
Oct. 10-16	15,578	399	57,456
Oct. 17-23	6,467	165	23,760
Oct. 24-30	11,866	304	43,776
Totals	1,358,736	34,839	5,016,816

*Estimated.

Trap No. 3

Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	43,751	1,121	161,429
Aug. 22-28	200,108	5,130	738,720
Aug. 29-Sept. 4	319,725	8,198	1,180,512
Sept. 5-11	318,303	8,161	1,175,184
Sept. 12-18	188,602	4,835	696,240
Sept. 19-25	530,602	13,605	1,959,120
Sept. 26-Oct. 2	37,085	950	136,800
Oct. 3-9	21,344	547	78,768
Oct. 10-16	13,212	338	48,672
Oct. 17-23	5,379	137	19,728
Oct. 24-30	5,440	139	20,016
Totals	1,683,551	43,161	6,216,048

Average No. of spores per trap for the season..........1,407,153
Average No. of spores per sq. in. for the season.......... 36,113
Average No. of spores per sq. ft. for the season..........5,162,234

An examination of the records from the spore-trap collections shows for the season of 1915 that the maximum spore-fall occurred previous to or during the first week of September, since there was a gradual decline in the number of spores falling on each square foot of surface following the first week of record.

For the season of 1916 there is a general agreement in the results from the traps located at the three different stations. During the first three weeks from Aug. 15 to Sept. 4 there was a gradual increase in the spore-fall, the maximum fall occurring in each case during the week of September 5-11. It is worthy of note that this week was also one of high wind velocity (see Fig. 2). Following the maximum there was a gradual decline in the spore fall through the last weeks of September; during the month of October, spores were still present, but in greatly reduced numbers. It has been shown in our experimental plantings that the highest per cent of smut infection occurred during the month following the maximum spore fall.* During this period there was plenty of moisture, the temperature conditions were favorable for smut, and the abundance of smut spores in the soil, gave as high as 41 per cent of smut from clean treated seed. These results point to the conclusion that wheat seeded in summer fallow during the period following the maximum spore-fall (last of September and first of October) is likely to be heavily smutted.

RELATION OF CLIMATIC CONDITION TO THE SMUT SHOWERS

Wind Intensity and Velocity. The climatic conditions of the Palouse country, previous to, including, and a few weeks following the threshing season are especially favorable for the wide-spread dissemination of the spores of stinking smut. The period is invariably characterized by bright sunshine, a very slight or often no rainfall, and a rather high wind velocity, especially at certain periods. The typical Palouse dust storm

*Heald, F. D. The stinking smut of wheat. Pop. Bul., Wash. Exp. Sta. 115:10-11. 1918.

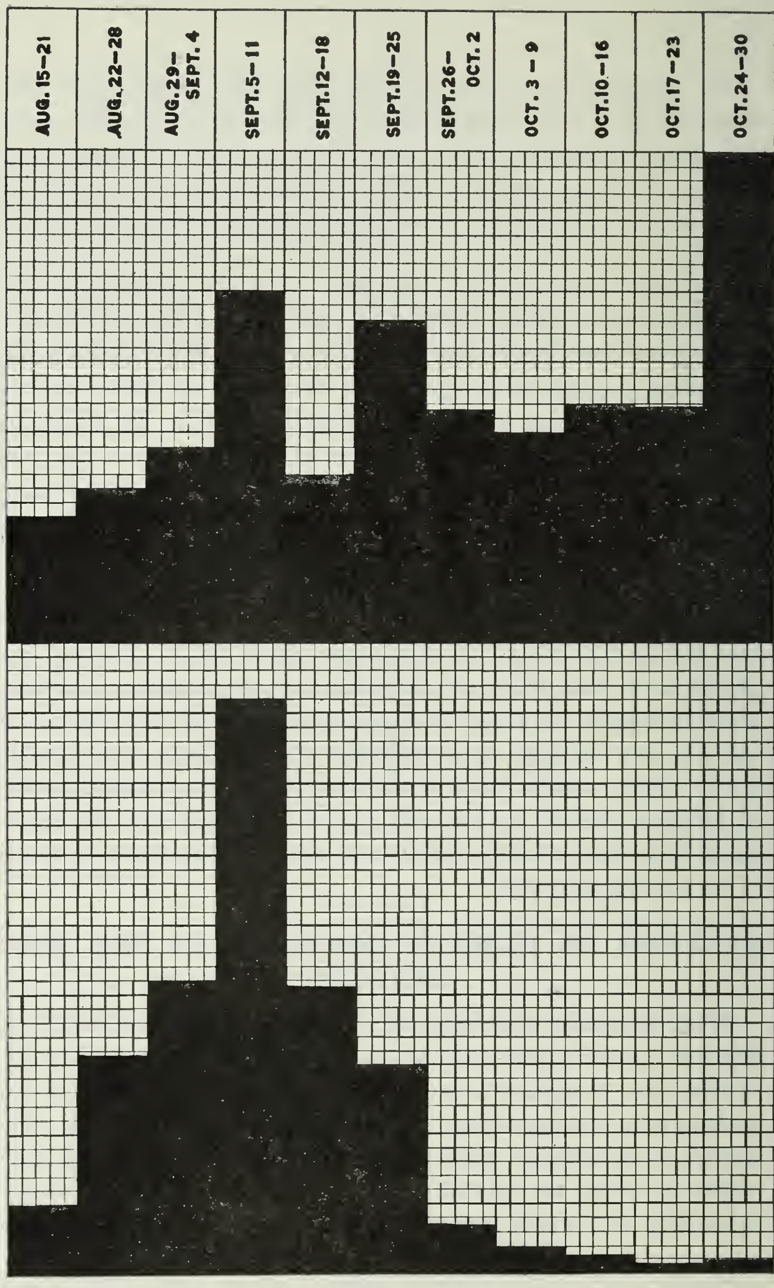

Fig. 2. Diagrams showing the spore fall and wind velocity from August 15 to October 30, 1916. The lower figure represents the spore fall, based on the total number of spores collected, and each square represents 2000 spores; the upper figure shows the wind velocity based on the average number of miles per day for 24 hours, for the week covered. Each square represents two miles. Diagram by D. C. George, formerly Assistant Pathologist.

is the culmination of a period of high wind velocity. This combination of factors makes the wheat straw very dry and brittle as well as causing a pronounced desiccation of the smut balls. The operators of threshing outfits take advantage of these dry conditions and run the separators at a very high rate of speed. This naturally causes the complete breaking up and crushing of the greater number of the smut balls, and as all machines are equipped with wind or fan stackers, great numbers of smut spores are thus shot into the air, and must ultimately find a resting place on either adjacent or distant fields.

Taking these facts into consideration it is interesting to note the relation of the wind velocity to the fall of the smut spores. The Division of Soils of the Experiment Station very kindly furnished us the wind records, covering the period during which the spore traps were set for the season of 1916. The results are graphically represented in the accompanying illustration. (Fig. 2.)

Rainfall. As previously mentioned there is a very small amount of rain during the harvesting and threshing season. The accompanying table (Table V) gives the rainfall for Pullman from June to October during the last three seasons.

TABLE V.

Rainfall in Inches at Pullman, June to October, 1915-1917

Month	1915	1916	1917
June	0.53	2.34	0.56
July	0.77	0.45	0.00
August	0.00	1.24	0.00
September	0.63	0.68	0.84
October	1.23	0.35	0.00

It may be noted that the season of 1917 was exceptionally dry, with a total of only .84 inch of rain during the four months covering harvesting and threshing operations in Eastern Washington and adjacent territory. Even during 1916, when the rain-fall was above normal for the period, the conditions were still very favorable for the wind dissemination of smut. We must conclude then that the average weather conditions which prevail in the wheat belt of Eastern Washington are conducive

to a wide-spread wind dissemination of the spores of bunt. Combine with this wide-spread scattering of smut a farming system which includes summer fallow and fall seeding and we have the explanation for the smut menace of Eastern Washington.

SUMMARY

Seed treatment, the effective practice for the control of bunt or stinking smut of wheat in other wheat-growing sections, has not been effective for winter wheat in the Palouse country.

Bunt is one of the cereal smuts in which the infection takes place only through young seedlings, either from seed-borne spores or from spores already in the soil.

The possibility of a wind-dissemination of the spores of bunt has been recognized. It has been shown that wind-borne secondary spores or sporidia play no part in the spread of smut, since there is no spread of smut from an infected to an uninfected field during a single season. Scattering of spores from smutted heads previous to harvest is of minor consequence, but during the threshing operations the smut balls are broken up and much of the smut dust is carried out through the stacker. Much of this smut dust must ultimately come to rest on the surrounding fields.

The wide-spread wind-dissemination of the spores of bunt was suggested by the visible clouds of smut dust which issue from threshing machines whenever the run is in a smutty field; the presence of smut spores on vegetation distant from any threshing operations; the production of smutty wheat when clean treated seed was sown on land, which had not previously produced a crop of smutty wheat; and also by the general ineffectiveness of seed treatment for fall-sown wheat.

Positive evidence of this widespread dissemination of the spores of bunt has been obtained by the microscopic analyses of the washings of foliage taken from stations distant from any threshing operations. This was further substantiated by the use of water spore-traps, which have made possible the de-

termination of the actual number of spores falling on a given area.

During the threshing season there is a "smut shower" or spore-fall in the vicinity of Pullman, which begins in August, increases to a maximum and gradually subsides. During the season of 1916 the maximum fall occurred from the 5th to the 11th of September. The exact time of the maximum will depend in part on the location, the period when threshing operations are the most numerous, and also upon climatic factors.

The dry conditions which prevail during the threshing period, together with frequent winds of high velocity, and a farming system which includes summer fallow and winter wheat, have combined to make wheat smut especially severe in the Palouse country.

The greater amount of winter wheat is seeded in summer fallow which has received countless numbers of wind-blown spores; the maximum amount of seeding generally follows the period of maximum spore-fall, and at this time both temperature and moisture conditions are especially favorable for smut.